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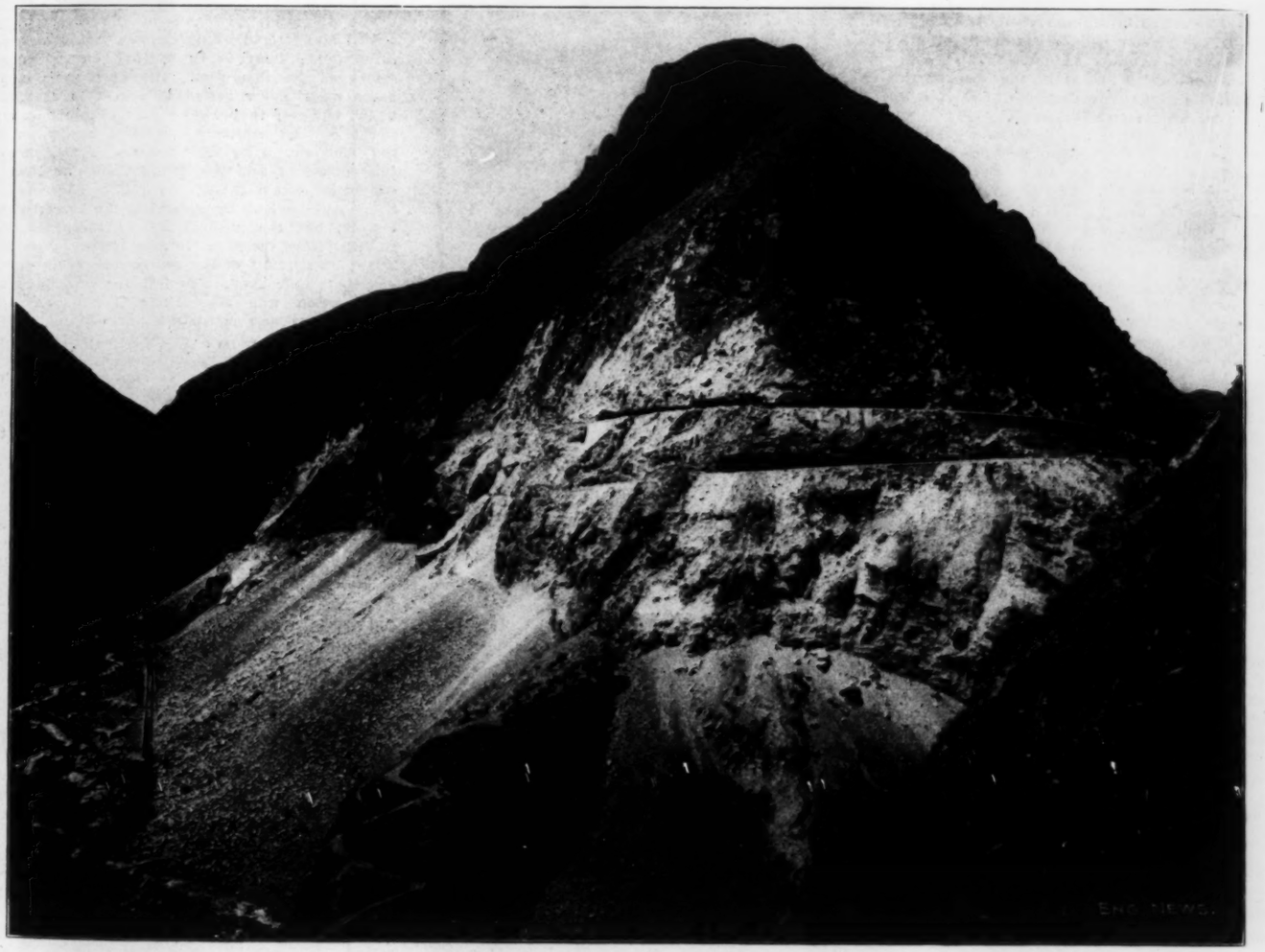
THE GUAYAQUIL & QUITO RY., IN ECUADOR, SOUTH AMERICA.

By John A. Harman.*

(With two-page plate.)

To build a railway from Guayaquil, its principal seaport, to Quito, the capital has been the dream of Ecuador for two generations, and the efforts of successive governments have been assiduously directed to this end for the past fifty years. The first real work accomplished in this direction was during the administration of Garcia Morena in the year 1871, when work was begun at the village of Yaguachi and extended a short distance towards Chimbo. In 1875 the road had been completed as far as Baraganetal, a distance of 28 miles. Some years later it was extended to Chimbo, 14 miles further, and connection was made with Guayaquil by steamer via the Yaguachi, Babahoya and Guayas Rivers. Matters remained in this condition until 1885, when an attempt was made to extend the road to Sibambe. Work was begun at Sibambe and Chimbo and seven or eight miles were graded at each end. The effort, however, ended in failure and work was dropped. In 1887 the line was extended from Yaguachi to Duran, a point on the Guayas River nearly opposite Guayaquil.

The government caused extensive surveys to be made between Chimbo and the summit of the Andes during the early nineties, but nothing in the way of construction was accomplished until 1889. Meantime the railway from Duran to Chimbo fell, through neglect, into a ruinous condition. From 1873 to 1894 no less than



THE SWITCHBACK ON PISTICHI NOSE. (MAXIMUM GRADE 4 TO 5%, COMPENSATED FOR CURVATURE.)

*Chief Engineer and General Manager Guayaquil & Quito Ry., Duran, Guayaquil, Ecuador.

twelve formal contracts were made between the government and private firms or parties, both Ecuadorian and foreign, for the construction of a railway which should connect the coast with the interior plateau; and in addition the government itself employed engineers and caused many extensive and expensive surveys to be made for its own account, especially between Chimbo and Sibambe, but every effort resulted in failure and financial disaster until 1898, when the government, during the administration of General Eloy Alfaro, entered into a contract with Mr. Archer Harman of New York for the rehabilitation of the old railway and ferry, and for the construction of the line from Chimbo to Quito. To-day, as a partial result of Mr. Harman's work, the railway has been carried beyond the summit of the great Andean barrier and trains are daily lifted from the coast to the plateau, a sheer vertical distance of two miles, from the hottest tropical region of the equatorial Pacific coast to the perpetual snows of Chimborazo. It is of this great work that we propose to give a brief description.

The causes which led to the government's failure to secure a railroad are easily discoverable, and may be summed up as follows:

(1) Lack of realization and appreciation of the cost and tremendous physical difficulties to be met and overcome;

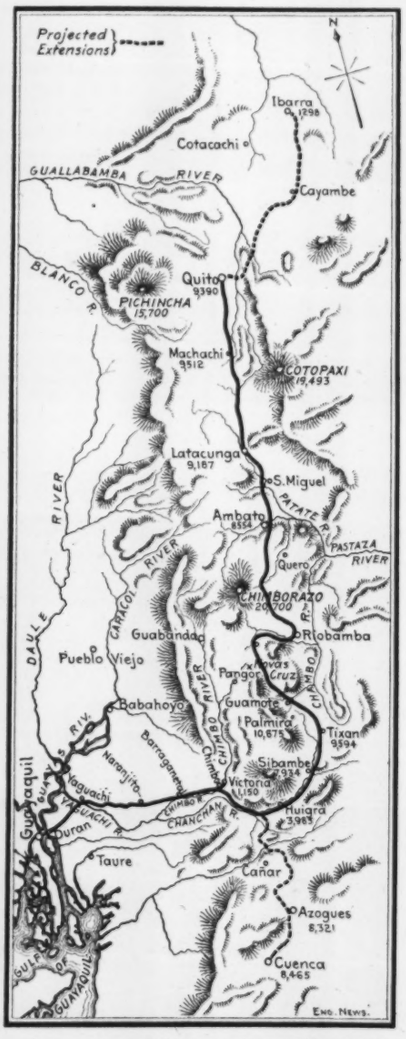
(2) Consequent failure to provide the necessary money, or, in lieu thereof, to create the necessary securities through which the money could be raised in the markets of the world;

(3) The former malodorous credit of the Government of Ecuador at home and abroad;

(4) Difficulties placed in the way of the enterprise by the Ecuadorians themselves due to internal strifes and jealousies.

Through patience and perseverance these difficulties have in the present instance happily been overcome, and for the purpose of this article, may be disregarded. Two contracts were entered into for the construction of the railway, and these were duly enacted into law by the congress of Ecuador. These contracts dealt quite specifically with the subjects of the finance, construction and operation of the railway. The principle of arbitration is adopted, both as regards the general relations between the government and the company and as regards technical questions when the Chief Engineer of the Railway and the Supervising Engineer of the government cannot agree. For the better understanding of the obligations and limitations of the company's engineers in locating and building the railway, a brief resume of the articles of the contracts which treat of the technical work is necessary. The company appoints a Chief Engineer and the government a Supervising Engineer, each of whom must be approved by both parties before entering upon their respective duties. In case of disagreement between the two, a third engineer is to be jointly selected by them to decide the points of difference.

The preliminary surveys had to be completed within nine months; the company had then to proceed to the final location and construction; the company was under obligation to begin construction within one year (including the nine months of preliminary location and to complete the railway within ten years unless impeded by war, natural catastrophe or epidemic, and in each such case the time for completion is extended three times as many days as the period of such interruption; the company cannot cease construction for longer than one year except as provided above; the company deposited a guarantee fund of $500,000 with agreed upon London bankers; the gage cannot be less than 40 English ins. (42 ins. adopted); the grade cannot be more than 3% except by agreement between the engineers of the government and the company, when it may be 4% in special cases (afterwards changed to 3½% for certain sections); the curves must have a radius as a rule of not less than 100 meters, and in no case less than 60 meters; cuts must have a width of not less than 4 meters and a minimum slope of ¼ to 1; embankments must have a slope of at least ½ to 1; tunnels must be at least 4 meters wide and a height of 2 meters above the cars (somewhat indefinite) rails steel and 50 lbs. to the yard (55 lbs. adopted); minimum number of ties to the mile 2640, dimensions 6 x 8 ins. x 6 ft. 4 ins.; rolling stock of first class and stations of good construction.

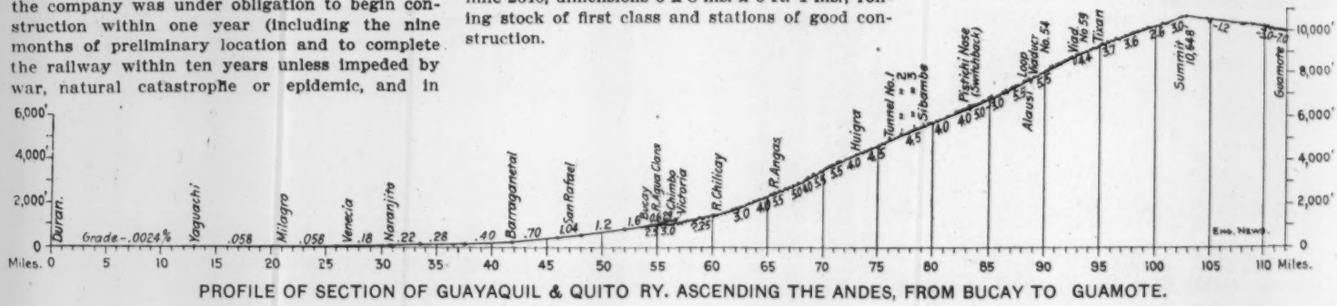


General Map of Guayaquil & Quito Ry.

In the fall of 1898 a corps of engineers was organized in the United States under Col. William Findlay Shunk as Chief Engineer, and in November of that year the corps started to work in Ecuador on the preliminary location. Topographically the territory through which the railway was to be built corresponds to the great natural divisions of Ecuador; namely, a gently rising stretch of coast country extending some fifty miles inland to the base of the mountain, then the western cordillera of the Andes rises abruptly and forbiddingly fifty miles to the summit, where the elevation is 10,648 ft.; from the summit to Quito the country is a rolling plateau lying between the parallel ranges of the Andes and crossed at right angles by low ranges, not unlike in effect the rungs of a huge ladder. The plateau is pierced longitudinally by a good road, the national carretera, and the location of the railway follows this road very closely and utilizes it in many places. The greater part of the population of Ecuador lives on this plateau.

There were two possible routes from the vicinity of Chimbo, the terminus of the old road, to the summit; one via the valleys of the Chimbo, Panza and Pangor Rivers to the Navaz Cruz pass, and the other via the valleys of the Chanchan, Alausi and Palmira Rivers to the Palmira pass. The latter route was selected, after careful study, and in June, 1899, final location, and a month later, construction, was begun.

The 3% grade provision of the contract required many tortuous developments and necessitated the railway being located on the steep slopes of the mountain. The Company's engineers were never satisfied with this location, which however they were forced to adopt on account of the arbitrary gradient conditions of the contracts. They had previously reconnoitered the Chanchan and Alausi quebradas and were convinced that a better line and a solider roadbed could be had by following the rivers more closely; but the natural fall of these streams was in places too great to admit of a 4% grade; while, on account of the narrowness of the canons, but little room was left for development, construction was accordingly begun on the adopted line and continued until March, 1900. The wet season of 1900 proved to be one of the most severe ever known in Ecuador, and the new work on the mountain sides was so damaged by slides and washouts, that the government, fearing another failure which might well prove a deathblow to all hope of securing a railroad to the plateau, finally agreed to allow a change in the gradient such as would enable the road to be located and built in the canons. Immediately the entire engineering and construction forces were moved onto the new line and the work of surmounting the Andes was entered upon with energy never before dreamt of. Meantime, all formalities having been complied with, the old road from Duran to Chimbo was turned over to the company, which then proceeded to rehabilitate it by rebuilding bridges and trestles, raising the track through the swampy sections, renewing ties, relaying the rails, ballasting, and changing the gage from 36 ins. to 42 ins.

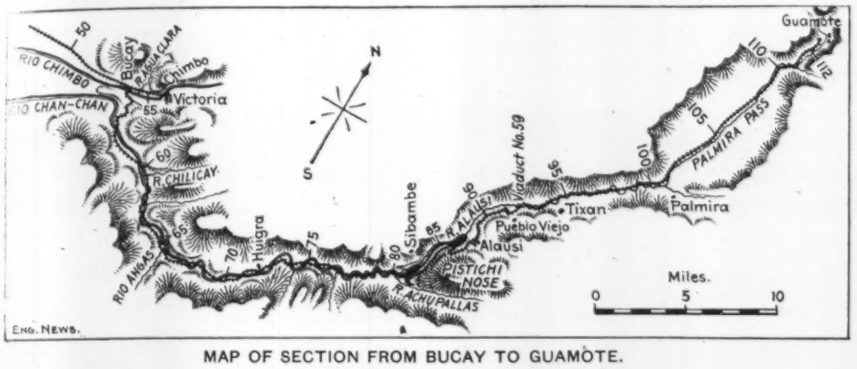


PROFILE OF SECTION OF GUAYAQUIL & QUITO RY. ASCENDING THE ANDES, FROM BUCAY TO GUAMOTE.

On the other hand the government admits construction material free of duty; protects employees of the company; exempts employees from military duty except in case of international war; furnishes to the company free of charge all or any roads or bridges belonging to it and practicable for railway purposes (this is a very important provision); provides right of way and land for stations, yards, etc., when owned by the government, etc.

The new line left the old at a point two miles west of Chimbo called Bucay Junction. From this point to Guamote the distance is 58 miles. For the first 20 miles, Bucay to Huigra, the conditions were most trying. The climate is hot, humid and oppressive at all seasons of the year

and during the winter this district is visited by torrential tropical rains; the country is thickly covered with jungle growth, which very gradually thins out. On account of traditional ideas of the unhealthiness of this region, no population existed and no one wanted to work in it. Subsequent events proved that this belt was no



MAP OF SECTION FROM BUCAY TO GUAMOTE.

more unhealthy than any other tropical country. However, to allay the feeling of uneasiness and guard against failure, it was necessary to make the most careful provision for food, shelter and medical attendance and supplies. No roads existed and the company was compelled, at heavy expense, to build a practicable mule trail from Bucay to Palmira. Subsequently thousands of employees and laborers were transported over and supplied by this trail with organized pack trains.

The engineers were organized under the direct supervision of Mr. F. W. Bennett, Assistant Chief Engineer, who became directly responsible to the Chief Engineer for the discipline, distribution, field and office work of the corps. Headquarters with drafting office, etc., were established at Victoria (near Chimbo). The mountain division was divided into three engineer divisions and residences were established every five miles, and an unusual number of helpers and servants was allowed; also all grades of engineers were mounted on mules furnished by the company. These precautions were considered necessary in order to preserve the health and efficiency of the corps. The engineer camps were kept separate, as a rule, from the construction camps, and at some distance from them.

An extensive medical corps was organized under the immediate direction of a Chief Surgeon, and a good hospital service was provided for; careful sanitary regulations were adopted and enforced; and every precaution was taken not only to prevent the outbreak of disease, but also to handle it properly, in case there was an outbreak.

These measures were eminently successful. We suffered very little from the ordinary tropical diseases—malaria, dysentery, yellow fever, etc. At one time smallpox appeared epidemically in a virulent form among the Jamaican laborers, but isolation camps and strict quarantines were established, and not only was the disease completely controlled, but it never again appeared. Frequent vaccination was resorted to, and great care was taken to get fresh points and have them constantly on hand. These were secured from the New York Board of Health and shipped to Ecuador on ice.

In other words, it has been our experience that there need not be any special danger to health and life in the tropics, if proper precautionary measures are taken. In the jungle belt, we encountered two or three varieties of poisonous snakes. The worst was the "Equis," or in English "X" snake, and we had a few deaths resulting from the bites of this reptile. At times we were troubled to some extent around the camps by tigers (jaguars). We have no recorded case however where one of these animals ever attacked a man, but they frequently attacked the mules and donkeys.

The grading was accomplished largely by casting and by wheelbarrow work, it seldom being possible to use scrapers, carts or cars. The grading was heavy throughout, especially between Pistichi and Tixan, where the yardage ran from 75,000 to 125,000 per mile, about evenly divided among earth, loose rock and solid rock.

There are two remarkable developments, rendered necessary by the rapid falling away of the Alausi River. The first of these, the Pistichi Nose, is a switchback, by means of which an elevation of 110 ft. is gained; and the second is the Alausi loop, by means of which an elevation of 290 ft. is gained. There are three tunnels, No. 1, solid rock, 163 ft. long; No. 2, gravel, timbered, 256 ft. long; and No. 3, solid rock, 69 ft. long. The Chanchan and Alausi Rivers find their beds in deep, narrow, tortuous canons, and to obtain the best ground for the roadbed, frequent crossings had to be made; added to this,

The Town of Naranjito, in the Tropical Belt.

these rivers drain an immense area of steep mountain slopes and there are numerous lateral streams; consequently, as may be expected, bridging is a striking feature of the road. So also is masonry, as, not only is there a large amount of masonry in the piers and abutments, but also in retaining and protection walls. Both cut-stone and concrete are freely used. The minor structure, of which there are a great many, consist of arch and flat top culverts, openways, vitrified pipe and track boxes. The retaining walls are sometimes built of dry masonry, but are usually laid in cement mortar. The protection walls are all laid in mortar. Both riprap and dry masonry were tried for these but on account of the furious floods common in the streams, they were not successful.

On the Alausi river, we have used a class of protection wall, which on account of the rapidity with which it was constructed, its cheapness and effectiveness, merits special mention. It is composed of old rails cut to proper length, set

A-TRUSSES USED TO SUPPORT FALSEWORK FOR CHANNEL-SPAN, VIADUCT NO. 2, GUAYAQUIL & QUITO RY.

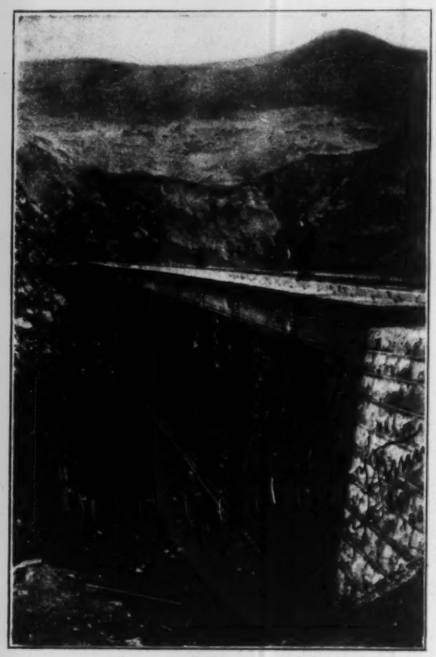
BRIDGE NO. 36 AND TUNNEL NO. 1, GUAYAQUIL & QUITO RY.

on end, bases outward, about 12 ins. apart in trenches and filled around with concrete; the rails are held in place by templates until the concrete sets; a light wall is then built behind the rails with ordinary selected river boulders so laid that the ends rest against the flanges of the rails and cannot be pushed outward. The faces of the walls are cemented and they are

ERECTION OF STEEL WORK, VIADUCT NO. 2.

then heavily backfilled with any material at hand. The result is a very neat appearing and effective protection wall. Masonry foundations as a rule gave no particular trouble.

The usual specifications for mortar, concrete and masonry were adopted, and the usual tests for strength applied.



Viaduct No. 2 After Completion.

At Bucay, the Chimbo River is crossed on bridge No. 1; three small bridges carry the road across small streams between the Chimbo and Chanchan Rivers, and the first crossing of the Chanchan is made at bridge No. 5, 2½ miles from Bucay. From this point to Pistichi the Chanchan is crossed 26 times, and lateral streams 13 times. From Pistichi to Palmira, the Alausi is crossed 22 times and lateral streams and quebradas 6 times. The total number of steel bridges on the mountain division is therefore 72, or 1.25 per mile, and the total weight of steel is somewhat more than 6,000,000 lbs.

The bridges are of course, both through and deck spans, the latter being used wherever practicable. I-beams are used up to 30 ft.; plate girders up to 80 ft. and riveted or pin-connected trusses for greater spans. The rivers are everywhere crossed by single spans.

No especial difficulty was experienced in erecting any of the bridges except No. 59 (viaduct No. 2). Temporary trestles for track and falsework were built from timber (except stringers) cut in the adjacent forests; after passing the tree line the timber was hauled forward to the successive sites on construction trains. The stringers used in temporary trestles were 12 x 12 in., Oregon Pine, and in permanent work 8 x 10 in., Oregon pine, packed in pairs. The numerous crossings caused great delay in tracklaying and finishing. Bridge 54 (viaduct No. 1) was erected with steam derricks without the use of falsework. Track was pushed ahead in some instances by laying temporary track on 60° curves around the heads of quebradas. Such track was operated with geared locomotives, Shay type.

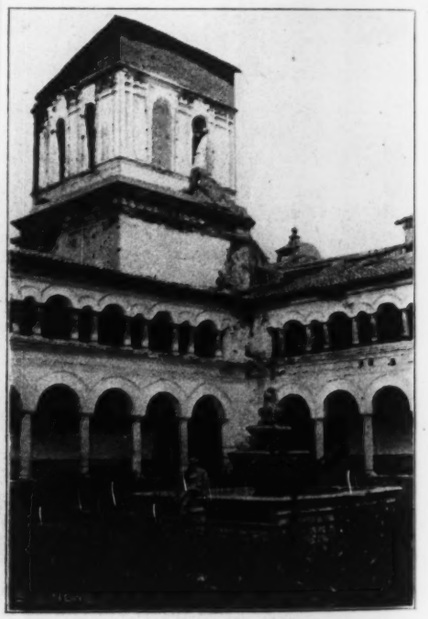
At bridge 59 (viaduct No. 2) great difficulty was encountered in securing the foundations for the tower footings, and in erecting and holding the false work. This was due to the fact that the bridge was erected during the wet season, when the river is subject to sudden and terrific floods. Track reached this viaduct just at the beginning of the wet season and for reasons of policy and finance, it was not considered advisable to postpone the erection of the bridge until the following dry season. Steel cableways securely anchored in concrete were stretched across the chasm; and carriages were operated over them by means of hoisting engines on each side of the chasm. The tower members were run out, lowered and held in place until secured; and in this way the tower was erected without the use of false work. After several failures to hold false work in the river for span No. 1, the plan of completely spanning the river with enormous "A" frames was adopted; a working platform was then erected upon these frames, and the bridge was erected.

Timber structures, of which there are 2,000 lin. ft. are both framed and piled; the piles are "Mangle," a timber native to Ecuador.

The ties are California redwood and native hard woods. On curves, tie plates are used on the redwood ties. The rails are 55 lbs. to the yard Am. Soc. C. E. section and specifications. Good ballast is abundant and easily secured and has been freely used to form an excellent roadbed.

The only uncommon features of the track laying are the "wide gaging" and superelevation due to the sharp curvature. "Wide gaging" adopted is 1-16 in. per degree of curvature from 6° to 22°, when the maximum of 1 in. is reached. The superelevation of outer rail is 3-16 in. per degree of curvature until a maximum of 5 ins. is reached. Both the "wide gaging" and superelevation adopted have proved entirely satisfactory.

The rolling stock is new and is composed of 45-ton Mogul engines and 50-ton geared engines and cars built especially for the Guayaquil and Quito Ry. Co. The capacity of the cars is 30,000 lbs. The only difficulty experienced in operating the railway is on account of the heavy grades, requiring trains to be divided into sections at the foot of the mountain. All locomotives and cars are equipped with Westinghouse automatic brakes and all cars are also equipped with hand brakes. The locomotives came out equipped with 8-in. air-pumps, but it has been found necessary to re-equip them with 9½ in. pumps. The ordinary trainload up grade is 80 tons exclusive of engine and tender; this gives about 45 tons pay freight. The ordinary trainload down grade is about 250 tons, or 150 tons pay freight. As was to be expected, numerous slides at first rendered the operation of the road difficult; but having passed through several wet seasons, the slopes have settled down and there is now no more trouble from slides than is to be expected on any mountain road. On the Palmira pass there are seven or eight miles of shifting sands, which at first gave some trouble; but this has been obviated by covering the roadbed with a mixture of heavy clay and gravel. In the jungle country great difficulty was experienced in keeping down the tropical growth which had great strength and constantly encroached upon the track. After considerable experimenting, a



Interior Courtyard of the Convent of St. Augustine, at Quito.

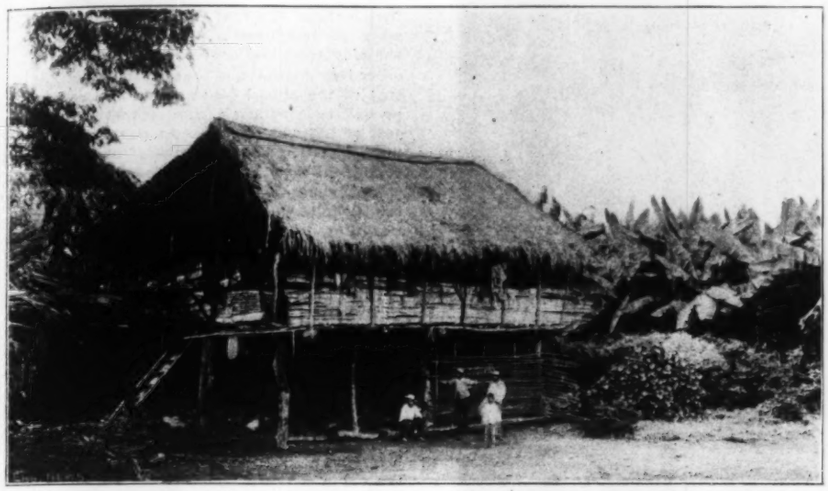
chemical process for the destruction of this growth was adopted, which has proven eminently successful.

The principal difficulties in locating, building and operating this road may be summarized as follows:

Entire absence of statistics of any kind of the rainfall, or maximum floods.

A firm conviction, on account of the many failures on the part of the people of Ecuador that a railway could never be built to the summit of the Ecuadorian Andes, or if it were built, that it could not be kept open and operated.

The hopeless lack of credit of Ecuador at home and abroad. The severe climatic conditions.



A PEON'S HOME IN THE TROPICAL BELT.

The extremely abrupt ascent of the Andes. The comparatively new geological formation of the country. The absolute lack of labor in the mountain sections. The distance from the bases of supply of construction and all other material. The torrential tropical rains in the low country, the tremendous floods in the mountain streams, and the shifting sands of Palmira.

All of these difficulties are practically overcome and the railway which connects sea-level tropical Ecuador with temperate Ecuador is completed and is in successful operation; and it is now the daily experience of passengers comfortably to ascend or descend the Andes in fewer hours than formerly it required days of such untold danger and hardship that few Ecuadorians of the coast had ever visited the capital, and few of those of the interior had ever seen the principal seaport of the country. For the first time in the history of the country the people are becoming acquainted with each other. A lucrative exchange of products has begun between the sections which in time will grow to an immense trade and will bind these two peoples, having one country, into a united people.

ENGINEERS' ESTIMATES OF COST.

By S. Whinery,* M. Am. Soc. C. E.

During the political campaign in the Autumn of 1903 in the State of New York, one of the most important questions discussed was whether the State should or should not undertake the reconstruction of the Erie Canal. The probable cost of the improvement was a notable feature of the discussion. It was known that the estimate of cost had been prepared after very careful and thorough surveys and investigation by a Board composed of a number of engineers of acknowledged ability and high reputation, and that the figures were, later, carefully studied and analyzed by the State Engineer and his staff, and a sum added to the original estimate to cover such changes in market values of labor and materials as had occurred in the meantime. In spite of all this, the adequacy of the sum named to carry out the improvement was questioned by a large number of intelligent people, among them able civil engineers whose judgment was entitled to respect. It was pointed out that every large project of canal construction or improvement that the state had ever engaged in had cost from 50% to 100% more than the engineers' estimates, and it was asserted that there was no assurance that the present enterprise would differ in that respect from its predecessors.

This is not an isolated case where engineers' estimates have been mistrusted. On the contrary, it is a fact that such distrust is more nearly the rule than the exception. It cannot be denied that the public is inclined to question the reliability of engineers' estimates generally. A disposition to discredit and even to scoff at them, regardless of the attainments and experience of the engineer by whom they were prepared, seems to be growing more common and pronounced among intelligent people and in the secular press.

The prevalence of such distrust is not only derogatory to the profession, but is most unfortunate for the best interests of the public. The cost of a projected work is undeniably one of the most important factors in the problem of its commercial value, and therefore of its expediency, and want of confidence in the estimated cost may, and undoubtedly often has, defeated meritorious enterprises.

It must be admitted that this distrust of engineers' estimates, if not wholly justifiable, is not without excuse. It is a fact that a very large number, perhaps a majority of the public works in this country, have cost more, and in not a few instances, twice as much as they were estimated to cost. Whether justly or unjustly, the responsibility for the result has been saddled upon the engineer who made the estimate. This is not surprising, since the public does not usually know all the facts, and is therefore unable to determine the true cause of excessive cost, and to place responsibility therefor where it rightly belongs.

Under these conditions it seems worth while for the profession to take account of the situation; to analyze the causes that so often seem to discredit their most carefully prepared estimates, and to consider what may be done to eliminate those causes. They owe it to the profession, as well as to themselves, that they should do this.

The public should, of course, bear in mind that the engineer is not and does not claim to be omniscient. All men, including engineers, are fallible. The engineer differs from other men of equal mental endowments only in that he has a certain amount of technical knowledge and training, supplemented by more or less experience in the particular line of work in which he is engaged. He is subject to the same mental limitations as are other men, and his judgment and opinions may therefore be erroneous, however much ability, training and painstaking care he may bring to his professional work.

But it should also be recognized that the engineer may be held morally responsible above others for those things only about which his special training and experience qualifies him to ascertain the facts and deduce conclusions with more certitude and authority than other men of equal general intelligence. As an abstract proposition this will hardly be questioned, and we may proceed to apply it to the particular department of engineering work we are considering—the preparation of estimates of cost.

Into every complete estimate of the probable cost of a projected engineering work the following elements enter:

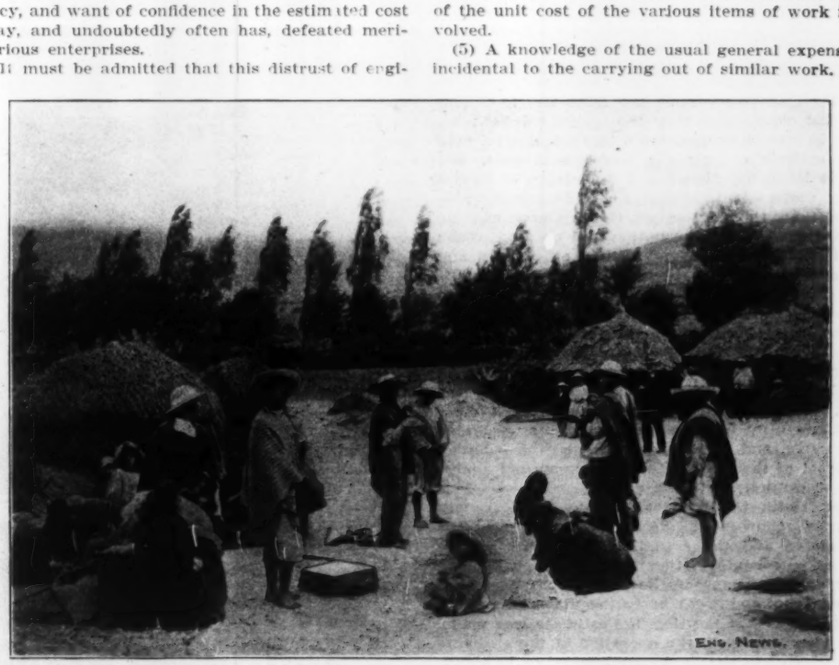
(1) A knowledge of the quantities and of the character of the work to be done.

(2) A knowledge of the physical conditions under which the work must be performed.

(3) A knowledge of the best methods of executing the work, under the conditions that will be encountered.

(4) A knowledge, gained from experience or information, of the cost of labor and materials, and of the unit cost of the various items of work involved.

(5) A knowledge of the usual general expenses incidental to the carrying out of similar work.



AGRICULTURE ON THE ECUADOR PLATEAU, WINNOWING GRAIN.

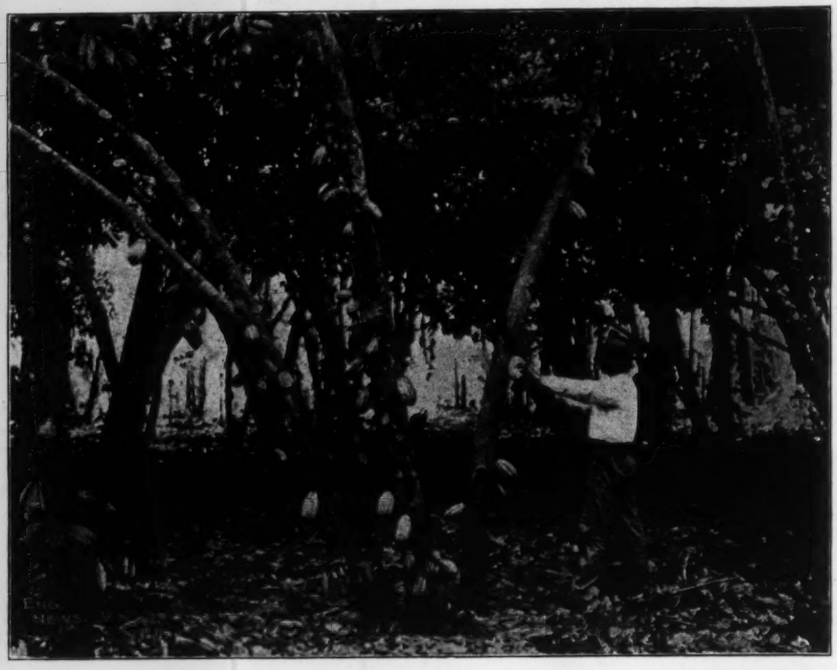
(6) A knowledge of the changes in the market values of materials and labor that may occur after the estimate is made up and before or during the progress of the work.

(7) A knowledge of the degree of ability and skill that will be exercised in prosecuting the work.

*Consulting Engineer, 95 Liberty St., New York City.

(8) A knowledge of the extent to which integrity and honesty will prevail among all those who are engaged upon or connected with the performance of the work.

(9) A knowledge of the fortuitous incidents that may attend the prosecution of the work.



CHOCOLATE TREES.

(10) An assumption that the plan and scope of the work upon which the estimate is based will not be altered.

The word "knowledge" is not here used in a restricted sense, since absolute cognition of all the facts and conditions is never possible; but in the sense of the best attainable information supplemented by sound judgment.

Now, in regard to numbers 1 to 5, inclusive, of these several elements, the engineer should be better able to ascertain the facts and to deduce correct conclusions than the unprofessional man. But in regard to numbers 6 to 10, inclusive, they are entirely outside the professional pale; and while large experience and knowledge of affairs may make his judgment somewhat more valuable than that of others, the engineer has no better sources of information and no more claim to the mantle of a prophet than other men, and he cannot, therefore, be held specially responsible for results dependent upon these elements. It this be so, he should avoid assuming responsibility therefor. In estimating the cost of any public work he should draw a sharp line of demarcation between the things he may properly be held responsible for and those that he may not. In the failure to make this distinction clear will generally be found the source of unreliable estimates, and to it may be traced the common distrust of them. Careful comparison and analysis of estimates of cost made before a work is begun, with the final statements of cost, will usually show that discrepancies between the estimated and the actual cost are due, not to errors or misinformation in regard to the quantity and character of the work to be done, nor to errors of judgment as to the unit cost of the various items at the time the estimate was made, but very largely to the operation of the elements enumerated in the items numbered 6 to 10 above. That expenditures due to these elements often make up a large percentage of the total cost of a public work is well known to every engineer of experience. That a suitable and liberal allowance should be made for them by the client and the public no one will deny. That they should be made a part of a strictly engineering estimate few who give the matter proper consideration will claim. If the engineer voluntarily assumes professional responsibility for them, the public cannot be blamed for accepting his assumed responsibility and holding him accountable therefor.

Let us examine a little more in detail those elements of an estimate of cost which fall properly within the province of the civil engineer, using for illustration a project to construct a canal.

The location and the dimensions of the proposed canal and its appurtenances having been decided upon, and the fullest possible investigations, tests for material, etc., having been made, the engineer will determine as accurately as practicable the quantity of excavation and embankment required, and the character of the material to be dealt with, and the quantities and character of the masonry, steel and other materials to be used in the locks, aqueducts, bridges, culverts and other structures necessary for the work. Having thus ascertained the quantities and the character of work to be done, he will next determine appropriate unit cost prices for each item of work, taking into consideration the market value, at that time, of each class of the materials and labor required, and of the physical conditions under which the work must be done, such as the facility and cost of transportation, climate, efficiency of labor, etc. He will next compute the cost of each item of work at the prices determined upon, and ascertain the total. To this total, he will add his estimate of the general expenses which his experience and information teaches him may be reasonably anticipated, such as engineering, superintendence, clerical work, interest and depreciation on plant, and any other legitimate items that enter properly into the cost of the actual construction of the work, and he will thus obtain a sum representing the total cost of the whole work. At this point his legitimate function as an engineer in estimating the cost of the work will end. The moment he goes a step beyond this he enters a domain of uncertainty and guesswork, and assumes responsibilities that do not belong to him as an engineer, since they have no connection whatever with the engineering features of the work. It is not within the province of the engineer to forecast the future market values of materials, labor or money; nor to weigh the probabilities of skilful or unskilful management; nor the moral character of those who may be connected with the work; nor the possibilities and magnitude of accidents; nor any of the multitude of things that usually enter into estimates under the convenient cloak of "contingencies." He is usually no better, and often not so well qualified to estimate the value of these things as are his clients or the public at large. When he undertakes to deal with them, he does so at the risk, not only of imperilling his own professional reputation, but of discrediting the profession itself. If he ventures an opinion at all on these elements of cost that are outside his province as an engineer, he should make it clear to all that he does so, not in his capacity of engineering expert, and that his opinions relating thereto are of no more value than those of other men of equal general intelligence.

The extent to which engineers, in making up estimates of cost, take these extraneous and fortuitous elements into consideration is much greater than appears upon the face of the estimates themselves. It is true that the item placed in the estimate under the head of "contingencies" is not usually a large one, but this item does not disclose the extent to which this class of elements enter into estimates. Almost every item is affected by the mistaken idea of "making it large enough" to cover all possible chances.

No better illustration of this could be presented than the estimate, heretofore referred to,

THE WEED-KILLING TRAIN; GUAYAQUIL & QUITO RY.

of the cost of reconstructing the Erie Canal. Replying to charges that this estimate could not be relied upon, a member of the Board that prepared it—himself an eminent engineer of acknowledged ability—said in an interview, which we may assume to be authentic, since it was not disclaimed:

> In all my experience I have never had to do with estimates where so great liberality was shown in providing for everything which would or could enter into the construction.
>
> We had in mind not only these instances which Mr. —— has cited, where the actual cost had overrun the estimates, but others as well, and we were determined that in this case we would allow so wide a margin for all contingencies, to so figure labor and material at the highest possible prices that our estimates would stand, and that the actual cost of the work when completed should not only not exceed the estimated cost, but be well within it. Not only did I have this in mind, but the other engineers and all who were connected with the figures were so minded, and every possible thing was provided for, all quantities were enlarged and the prices put high in order that we might discount this very criticism when it comes, as it has now.

While it appears further on in the interview that the elements of possible unskilful or dishonest management were not assigned a value in the estimate, it is openly claimed, as a virtue not to be overlooked, that it included "all possible contingencies, not excepting the probable future market value of material and labor."

We need not stop here to argue the truth of the proposition that the engineer who knowingly overestimates the cost of a public work may be, and usually is, as culpable as the one who underestimates that cost, particularly if the overestimate results from the excessive valuation of things outside of his professional domain, and about which the engineer is not better able to judge than the non-professional man. In the particular case under consideration, it is conceivable that the improvement, regarded by many as of vital importance to the people of the state, might have been defeated solely because its estimated cost was so great as to make its commercial success at least doubtful. If the makers of this estimate really believed, as is implied in the interview quoted, that the sum named was excessive, what justification could they offer for deliberately deceiving the people of the state in a matter of so much importance? Is not the fact that they purposely named a sum materially exceeding that which, in their deliberate judgment, they believed the work should cost, alone sufficient to discredit the estimate in the eyes of intelligent people? These questions are not asked to impugn the motives or the professional conduct of the eminent men who prepared this estimate. At the worst it may be said that they conformed to a pernicious custom, originating in creditable motives, that has grown up in the profession.

Making further use of this particular case for the purpose of illustration, we may enquire what was the legitimate and proper duty of this board of engineers in preparing this estimate? What were their clients, the people of the state, warranted in expecting from its members as engineering experts?

Obviously they were retained to report upon matters about which they were supposed to be more competent to judge correctly than non-professional men. The board might therefore have said (with regard to its estimate of cost) something like the following:

> The surveys and examinations for the proposed improvement have been made with unusual care and thoroughness and plans and outline specifications have been worked out and considered, with great care; the quantities and the character of the work involved have been ascertained as fully as is practicable before the work is actually under construction, and we have made liberal allowance, where any uncertainty exists in this respect. In estimating the probable cost of the work we have based our figures upon the present market value of materials and labor in the region where the work is to be done. The unit prices applied to the several kinds of work, are based upon our personal knowledge and experience, supplemented by all the information we have been able to obtain about the cost of similar work, the special physical conditions that are likely to be encountered in this particular work having been given full consideration. Under the head of general expenses we have added such sums for engineering superintendence, clerical work, and interest and depreciation upon plant, as in our opinion should fully cover these items of cost. The estimate assumes that the work will be conducted with the average skill and efficiency. It makes no allowance for possible changes in the plan or scope of the improvement we have outlined, nor for changes in the market value of material and labor. No allowance is made in the estimate for possible improper or dishonest administration; nor for casualties and contingencies which cannot now be foreseen, but which, judging from our experience on work of similar character, should not exceed —— per cent upon the total we have reported.

This is, of course, a bare skeleton of what a report might say (about which something will be said later on), but it outlines the only position the engineer can take with safety to himself and justice to his client. It embraces everything that the engineering expert can safely express a definite judgment upon, and does not attempt to forecast, or to place a value upon the result of events and circumstances about which he neither does, nor can know more than other men of equal general intelligence, and for which, therefore, he may and should disclaim special responsibility.

An estimate formed along such lines would have a positive and definite value, and should command respect and confidence, because it would be founded upon ascertainable facts and expert knowledge and judgment, and would be free from any element of divination. If made by competent engineers, it should be authoritative and trustworthy within the field it assumes to cover. The client, whether an individual or the public, would then be compelled to make such allowance for possible maladministration and fortuitous contingencies, as his judgment might dictate, and he would assume the responsibility therefore. Since the administration will usually be in his control, it is proper that he should bear the responsibility for any increase of cost due to mismanagement or dishonesty.

It may be objected that clients would not be satisfied with such an estimate because it does not purport to cover the whole possible cost of the contemplated enterprise, which is what the client wishes to know. Doubtless such a departure from prevailing practice would at first be resented. But clients would soon come to understand that it is better, for their own interests, to have reliable figures based upon known data and expert judgment, covering a definite part of the cost, than the combination of fact and prognostication now commonly offered under the guise of engineers' estimates of cost.

It may also be urged that extensive experience and observation enables the engineer to appraise the value of fortuitous elements more correctly than can the non-professional man. To this it may be replied that these elements, from their very nature, are not subject to known laws, and experience is of little value in predicting their magnitude. It is true that the theory of averages or of probabilities might be introduced, but these do not yield results that are entitled to a place in the definite values of an individual estimate. They are sufficiently recognized when the client is told that the class of items excluded do not usually amount to more than a stated percentage of the ascertainable cost of the work.

It may be still further objected to an estimate of this character that its substantial accuracy could not be established, or the judgment of the engineer vindicated from the actual results of construction; that careless or unskilful management might result in an increase of the quantities, and would surely increase the unit cost of the work, regardless of contingent or fortuitous elements, and that it would be almost, if not quite impossible to establish the true cause of the increase of cost thus brought about. Assuming that this be wholly true, the position of the engineer, in the eyes of the public, could not be more unsatisfactory than it now is, and he could defend himself with a clear conscience, having discharged his duty in strict accordance with his knowledge and judgment. The assumption would not be true in a very large number of cases, since the results upon similar work under good management could usually be adduced to support his estimates.

The effect of inflated estimates in encouraging, or at least excusing, extravagant and reckless expenditure must not be overlooked. The fact that an enterprise has been carried out at a cost within the engineers' estimate is not only commonly held to vindicate the administration of the work; but clients and the public may be thus deceived into the belief that their money has been judiciously and honestly spent when the opposite may be true. So long as the expenditure is kept within the estimate, clients are likely to be lulled into the belief that everything is all right, and may not, therefore, exercise the caution that they otherwise would. Such a condition may offer opportunity and wide latitude for carelessness and even dishonesty that would not be possible were clients made watchful and alert by the fact that the cost was exceeding the estimates. This consideration alone should impel the engineer to adhere closely to what he believes should be fair and reasonable figures in preparing estimates, since it would be a breach of trust for him to aid and abet wrong-doing, even unintentionally.

Within the limits here outlined, an estimate of the cost of a proposed engineering work should be as full and complete as the available data will permit. A bare itemized statement of quantities, prices and amounts is never satisfactory. The facts and conditions upon which the figures are based should be stated with sufficient fullness to disclose the data and the reasoning upon which the conclusions are founded. The extent and character of the surveys and examinations made, and the measure in which they are regarded as adequate to disclose the quantity and the nature of the work to be done, should be stated. Definite outline plans and specifications showing the amount, nature and quality of the work upon which the estimate is based, should accompany it. The assumed market value of materials and labor, at the time, should be recorded, and conditions that may modify these, as applied to that particular work, stated. In short, sufficient data should be given to enable another engineer to understand and verify the whole estimate. That this is not usually done, almost any engineer who has had occasion to review estimates will testify. The absence of such detailed information is a frequent cause of the wide differences that sometimes appear in the estimates of different engineers, which tend to increase the general distrust of the public in engineers' estimates.

As an example, hydraulic cement concrete now often constitutes an important part of engineering work. Its unit cost varies within quite wide limits, depending upon the cost of the materials delivered upon the work, the ratios in which these materials are used, the cost of the necessary labor, the manner in which the mixing is done and the concrete placed in position, the cost of the necessary forms or molds, and the conditions under which the work must be done. All these details should, therefore, be shown in making up the unit cost used in the estimate. Even in the case of earth excavation and embankment, usually regarded as the items of work requiring least explanation of details, the manner in which the unit cost is arrived at should be clearly outlined. The question of the basis of payment, whether as excavation alone, or embankment alone, or what is known as "paying both ways," or of paying for whichever shall be in excess on each section or upon the whole; the allowances made for "overhaul" and "shrinkage," and any special conditions that are likely to be met with, are all elements that enter into the fixing of the unit price, and should be made clear. The expenses that go to make up "general expenses" should be itemized as far as possible, and the manner in which the allowance for use of, and interest and depreciation on plant is arrived at, should be recorded.

While no two engineers might arrive at exactly the same results in making up such an estimate, it might reasonably be expected that their differences would be confined within comparatively narrow limits, since the fortuitous and unknowable elements, heretofore referred to, which offer the widest latitude for difference in judgment (or rather guesswork) would be excluded. It would deal only with matters about which the knowledge and experience of the engineer renders him competent to express an expert opinion. Within the limits it assumed to cover, it might be safely relied upon by the client and the public.

It may be argued that, regardless of the attitude the public might assume, it would be very difficult to bring about in the profession itself so radical a change in the practice of making up estimates of the cost of proposed work. Doubtless it would meet with opposition at first. But if it be true that it would not only conduce to the good name of the profession itself, but would also safeguard the reputation of the individual engineer, and would in the end be in the interest of, and would command the approval of the pub-

lic and restore its confidence in this branch of the engineer's work, the effort to bring about such a reform would be well worth while.

In the present condition of lack of confidence, both inside and outside the profession, the matter certainly merits the most serious and careful consideration.

PROPOSED CHANGES IN THE SEWAGE DISPOSAL WORKS OF DARWEN, ENGLAND.

Some idea of the procedure commonly followed in obtaining authority to make permanent loans for municipal improvements in England and Wales may be gained from the account, printed below, of a recent hearing at Darwen, England, on a proposed loan for remodeling the sewage disposal works. The account may also be taken, broadly speaking, as an illustration of the changes in methods of sewage disposal now in progress in Great Britain. The account is taken from the London "Surveyor," as follows:

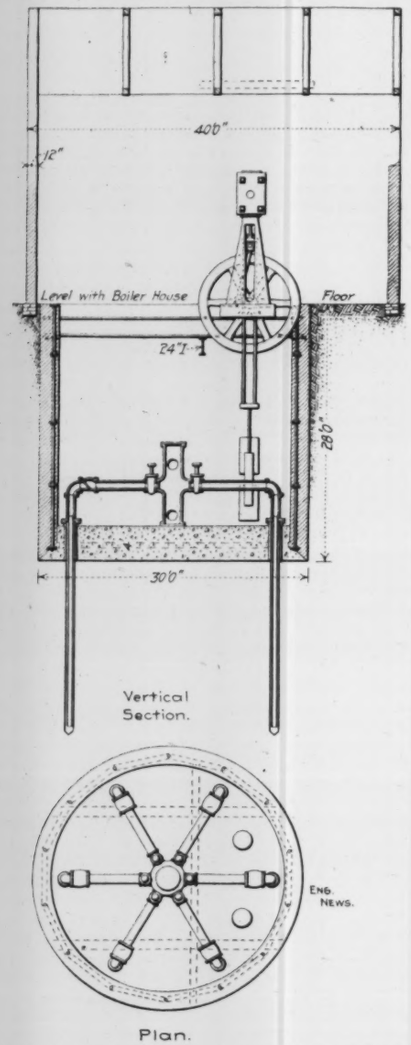


Fig. 1. Plan and Section of Pump Well, Middleton, O, Water-Works.

Mr. R. H. Bicknell, M. Inst. C. E., held an inquiry last week at which the details of proposed additional sewage disposal works were laid before him. With a present population of 39,000, living on an area of 5,919 acres, of which 5,704 acres are affected by the proposed works, it was stated that the consumption of water, for all purposes, amounted to only 15 gallons (18 U. S. gals.) per head per day, a figure which caused the inspector to comment upon its smallness.

As regards the sewage works, the proposed additional loan of £14,000 ($71,000) had been decided upon as the best means of giving effect to measures resulting from six years' study of the problem, but of this sum £2,000 ($12,635) was intended to cover excess expenditure over previous loans. In this connection, the inspector stated that the Local Government Board would require full details in parallel columns, showing how the excess expenditure had been incurred, a matter which would involve some time, as Mr. R. W. Smith-Saville, the present borough surveyor, was not in office when the previous loan was applied for. As regards the £12,000 required for new works, the borough surveyor said that the scheme had been designed with special reference to the increased flow to be dealt with in times of storm and the desirability of reducing the volume of sludge. The latter object would be attained by the adoption of septic treatment in place of chemical precipitation, and the septic effluent would be treated bacterially.

The area of the existing works is 27 acres, of which about 7½ acres are taken up by tanks, etc. The dry-weather flow of sewage is 750,000 gallons (900,000 U. S. gals.) per day, and the town's sewerage works are mainly on the separate system. The existing chemical precipitation tanks, six in all, have an aggregate capacity of 860,000 gallons (1,032,000 U. S. gals.), rather more than a day's dry-weather flow, and are in future to be used as septic tanks, the whole volume of sewage passing through their entire length. The effluent from the tanks is to be delivered into bacterial filters through revolving sprinklers. The twelve existing clinker and sand filters are to be improved and used for this purpose, and six additional filters are to be constructed. The whole of the filters will have a working depth of 8 ft., and they will be composed of hard vitrified ironworks slag, washed, screened and broken by hand into suitable sizes. It is proposed to treat storm water, when necessary, up to 3,000,000 gallons (3,600,000 U. S. gals.) per day, equal to four times the dry-weather flow. There will be, for this, a new elongated tank, of 500,000 gallons (600,000 U. S. gals.) capacity, with sloping sides, specially adapted for use on the septic system. Three Dortmund cones at the inlet end will enable the sludge to be withdrawn without disturbance.

It should be understood that Mr. Bicknell represented the Local Government Board at this hearing and that after all such hearings the inspector or inspectors detailed for the purpose report to the board and that finally the board grants or denies the application for a loan or requires amendment of the proposed plans.

THE ADDITIONAL WATER SUPPLY OF MIDDLETOWN, OHIO.

The present water supply for Middletown, Ohio, is taken from an open well, 25 ft. in diameter and about 28 ft. deep. As an additional supply was called for, it was determined to sink another well, of the same diameter and depth, near enough to the old well to enable the new pumping engine to be under the control of the engineman in charge of the old plant. The situation required a treatment that was somewhat different from the ordinary arrangement, and this is here described.

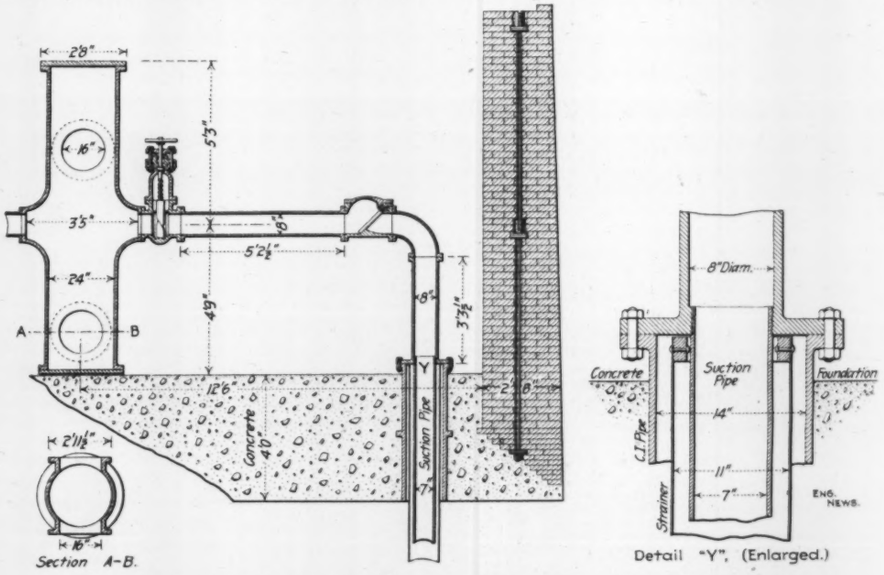


FIG. 2. DETAILS OF SUCTION PIPE CONNECTIONS TO WELL TUBES.

The new well was sunk by means of an oak shoe or ring 30 ft. in outside diameter, and fitted with a wrought-iron cutting edge bolted to the outside of the bottom of the oak ring and projecting 8 ins. below it. On this shoe the brick masonry was laid in Portland cement in a wall 2 ft. 6 ins. thick, and 1¼-in. iron rods were built in the wall vertically and 2 ft. apart. These rods passed through the wooden shoe and were secured by broad washers and nuts at each end. The bottom of the well was closed by a concrete floor 4 ft. thick, pierced by six pieces of 14-in. iron pipe, each 6 ft. long and flanged at the upper end and in the center of the concrete.

Through these openings six 11-in. perforated well pipes or "Cook strainers" were driven to a point 24 ft. below the top of the concrete floor. Inside each of these strainers was placed a 7-in. suction pipe leading to the pump and extending nearly to the bottom of the strainer, the latter being closed at the end. This is one of the novel features of the plan; the usual method pursued is to locate the suction pipe above the strainer. The advantage of this plan is that the suction pipe will draw the water from whatever height it may stand around the strainer and secure all the water in the neighborhood. The strainer pipes are secured by a flanged joint to the 8-in. casting leading to the central suction chamber, and into this casting the suction pipe is screwed, making an air-tight joint at the top of the strainer and at the level of the concrete floor.

The main suction chamber is located in the center of the well, the six suction pipes radiating from it, and each of these pipes is fitted with a gate and a check valve. The casting for the suction chamber is 10 ft. high and 24 ins. inside diameter, the suction pipes entering about the middle of the vertical dimension. In this chamber are four 16-in. outlets leading to the pump. The pump itself is of the usual, outside-packed vertical plunger type, and was located at the level of the top of the well. This plant was designed by Mr. James R. Maxwell, Consulting Engineer, Cincinnati, O., to whom we are indebted for these details.

TESTS OF REINFORCED CONCRETE BEAMS.*

By Arthur N. Talbot.†

It is intended here to review some of the results of tests of reinforced concrete beams made recently at the University of Illinois. In the investigation, an endeavor was made to determine the horizontal deformations of the beam during the progress of the loading and to find the amount of the stresses taken by the steel and by the concrete. Some attention was given to the effect of a change in the amount of metal used, the relation between elastic limit of metal and strength of the beam, and the position of the neutral axis.

*A paper read at the annual convention of the American Society for Testing Materials, June 16 to 18, 1904.

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Twenty-two rectangular reinforced concrete beams 15 ft. 6 ins. long, 12 ins. wide, and 13½ ins. deep were tested. The center of the metal reinforcement was 12 ins. below the top of beam, but in some of the beams the rods were inclined or turned up at the ends. The span was 14 ft. The loads were applied equally at two points, which divided the span into three equal parts. This loading gives a bending moment for the applied load of 1-6 W l at all points between the loads.

Chicago AA Portland cement bought in the open market was used; a 1 to 3 mortar gave 233 lbs. in 7 days and 340 lbs. in 60 days. The sand was fairly clean and well graded in size and contained 29% voids. The stone was crushed limestone and ranged between ¼-in. and 1½ ins. in size, and contained 44% voids. The concrete was by loose volume 1 cement, 3 sand, 6 stone. Concrete beams having the dimensions of the reinforced concrete beams gave a modulus of rupture of 343 lbs. per sq. in., counting both the applied load and the weight of the beam. Six-inch concrete cubes gave an average compression strength of 2,030 lbs. per sq. in.

For the reinforcement plain round rods, plain square rods, Johnson corrugated bars, Thacher, Ransome and Kahn bars were used. The amount of reinforcement varied from 0.6 sq. in. of metal to 2.4 sq. ins., or from 0.42% to 1⅝% of the area of concrete above the center of the reinforcement. The yield point of the plain bars and of the Kahn and Thacher bars was between 32,000 and 35,000 lbs. per sq. in. The yield point of the Johnson bars was between 55,000 and 60,000 lbs. per sq. in. The yield point of the Ransome bars, not determined, was also high.

The beams were made directly on a concrete floor, except that a strip of building paper was placed under them, and they were not disturbed from this position until taken to the testing machine. The beams were tested at 60 days' age, the greatest variation from this being three days. This age was sufficient to reduce the variations in properties of the concrete due to differences in moisture and atmospheric conditions to a relatively small amount. Care was taken to have the work of mixing done uniformly and the general appearance and behavior of the concrete was quite uniform.

The tests were made on an Olsen testing machine of 200,000 lbs. capacity, with beam attachment. The extensometer device was carefully planned and calibrated, and it is believed that the measurements are trustworthy. Each frame of the extensometer device was attached to the beam by two pairs of screws, one pair generally being placed against the sides of the beam 1¼ ins. below the top of the beam and the other pair 1¼ ins. above the bottom of the beam. The gage length was generally about 61 ins. Four extensometers, modified forms of the Johnson instrument, were used, their position being above and below the contact screws, but directly in line with them. They read to 1-10,000-in.

DIAGRAMS.—Several typical load-deformation diagrams are given showing the relation between the applied load as ordinates (not including the weight of the beam which has already stressed the fibers when the instrument is read at zero load) and the deformation per unit of length as abscissas. From the readings of the extensometers (which it will be remembered were above and below the beam and hence have magnified values) the shortening of the upper surface of the beam was calculated, and this shortening was divided by the gage length which was in the neighborhood of 61 ins. This gives the compressive deformation per unit of length marked "Upper fiber" on the diagrams. Similarly, the elongation of the beam at the level of the center of the steel reinforcement was calculated, and this elongation divided by the gage length is marked "Steel" on the diagram. The calculations are based on the assumption that a plane section before bending remains a plane section after bending, and that the steel elongates the same as the concrete at the same depth. Generally the extensometers were taken off at the maximum load. The deflections at the middle of the length of the beam are also shown, a second scale of abscissas being used for this. The upper part of the diagrams gives the successive positions of the neutral axis obtained under the same assumptions as above. The ordinates denote this position in per cent. of the distance from the top of the beam to the center of the steel reinforcement for the applied loads given on the scale of abscissas.

TABLE.—The table gives the stresses found in the steel reinforcement and the resisting moment developed by the steel at certain loads, as calculated by the methods and assumptions here described. The column "Load considered" is the applied load somewhat below the maximum load and for which elongations and shortenings are definitely known and hence is the load used in the calculations for the succeeding columns. The stress in steel is based upon the observed deformations using the coefficient of elasticity found for the naked steel bars. The symbol m represents the distance of the neutral axis below the top of the beam, found as explained hereafter. The position of the center of gravity or centroid of the compressive stresses is taken in the calculations to be four-elevenths of the distance down to the neutral axis. This position is the result of analysis which cannot be given here, and is

VIEW SHOWING TESTING APPARATUS AND METHOD OF TESTING REINFORCED CONCRETE BEAMS AT THE UNIVERSITY OF ILLINOIS.

close to the usual assumptions which take into account the varying relation between stress and deformation in concrete; nor will the difference between this position and that resulting from the assumption of a constant coefficient of elasticity give a serious error. The moment of resistance of the beam, neglecting tension in the concrete, is found by multiplying the tension in the steel as found by the deformation and coefficient of elasticity by the distance from the center of the steel to the centroid of the compressive stresses in the concrete, $d - \frac{4}{11} m$, where d is the vertical distance from the top of the beam to the center of the steel reinforcement. It is readily seen that since the compressive stresses here considered are equal to the tensile stresses of the steel this calculated moment of resistance is the same as if the moments of the tensile and compressive stresses had been taken about the neutral axis and added together. The method has the advantage that the compressive stress at the upper fiber does not enter into the equation. Of course it must be known in some way that this stress is within the ultimate strength of the concrete. The column $\frac{Mr}{Mb}$ gives the ratio of the bending moment at any point between the loads to the resisting moment calculated as shown above. The last column gives the same ratio with the bending moment augmented by the estimated proportion of the weight of the beam which the broken tensile fibers of the concrete has transferred to the steel. Further uses of the table will be apparent in the further reference to it.

GENERAL PHENOMENA OF THE TESTS.—Four stages of flexure are noticeable during the application of the loads. Through the first stage, as the load is applied, the action of the beam and the changes in deformations of upper and lower fibers are similar to those in plain concrete beams, modified of course by the metal reinforcement; and the resistance of the tensile stresses of the concrete is plainly apparent. When a load of about 4,000 lbs. for 4-10% reinforcement and of about 6,000 lbs. for 1.5% reinforcement is reached (equivalent to about 250 lbs. per sq. in. tension in the extreme fiber of the concrete for its share of the applied load and 350 lbs. per sq. in., when the weight of the beam is considered), the second stage begins. The steel elongates more rapidly with the applied loading, there is a similar increase in the compression of the concrete, the neutral axis rises, and there is a marked change in the character of the load-deformation diagram. While no cracks are visible to the naked eye at this second stage, it is evident that much of the tensional value of the concrete has been lost. This stage may be called the readjustment stage. During the third stage the increments of the deformation of the steel are closely proportional to the increments of the loading, as shown by the straight line of the load-deformation diagram, and the compressive deformations generally approximate a straight line. During this stage vertical cracks appear, generally quite numerous and well distributed along the middle third of the length of the beam, and grow in width; but this appearance is not accompanied by any change in the character of the load-deformation diagram. This stage continues until a point at or near the maximum load is reached, except with those beams having an excess of reinforcement. The last, or stage of failure, begins at or near the maximum load. The beam deflects more and more, the load required to balance the scale beam becoming less and less. The steel stretches rapidly the neutral axis changes position, and there is a more rapid compression of the upper fiber of the concrete, until finally the concrete crushes out at the top of

TABLE SHOWING RESULTS OF TESTS AND THE FIGURED MOMENTS OF REINFORCED CONCRETE BEAMS TESTED AT THE UNIVERSITY OF ILLINOIS IN 1903-4.

Beam No.	Amount and kind of reinforcement.	Area of metal, sq. in.	Extensometer gage length, inches.	Maximum load, pounds.	Load considered, pounds.	Total elongation of steel, inches.	Stress in steel, lb. per sq. in.	Moment arm. m. inches.	Moment arm. d − 4/11 m. inches.	Resisting moment. M_r in.-lbs.	Bending moment. M_b in.-lbs.	$\frac{M_r}{M_b}$	Estimated total bending moment M_r' in.-lbs.	$\frac{M_r}{M_b'}$
21	3—½" Plain round	.59	60.5	9,000	8,000	.0665	32,900	4.00	10.55	204,000	224,000	.91	261,000	.78
19	3—⅜" " "	.59	60.5	9,200	9,200	.0755	37,400	4.50	10.36	228,000	257,600	.885	294,600	.775
16	3—½" Plain square	.75	60.75	9,900	9,900	.065	32,100	4.50	10.36	250,000	277,200	.90	313,200	.80
17	3—½" " "	.75	60.5	10,000	9,500	.059	29,300	4.25	10.45	229,000	266,000	.86	302,000	.76
27	4—¾" " "	2.25	56.75	26,900	25,000	.066	34,900	6.38	9.68	760,000	700,000	1.085	725,500	1.05
9	3—½" Ransome	.75	60.75	22,800	18,000	.142	70,000	3.75	10.64	559,000	504,000	1.11	540,000	1.035
15	3—¾" Thacher	1.20	61.25	18,400	15,500	.0715	35,000	4.75	10.27	431,000	434,000	.99	466,000	.925
10	3—¾" "	1.20	60.87	16,600	14,500	.065	32,000	4.75	10.27	394,000	406,000	.97	438,000	.90
22	3—¾" Kahn	2.40	56.75	24,400	22,000	.064	33,800	7.87	9.14	743,000	616,000	1.205	641,000	1.16
4	5—⅝" "	2.00	61.25	23,000	21,000	.069	33,800	5.62	9.96	673,000	588,000	1.14	615,000	1.095
14	4—½" "	1.60	61.5	17,200	17,000	.062	30,200	5.50	10.00	483,000	476,000	1.015	505,500	.955
5	3—½" "	1.20	61.25	15,000	13,000	.0625	30,600	5.00	10.18	374,000	364,000	1.03	396,000	.945
28	6—⅝" Johnson	2.19	60.25	34,300	31,000	.101	50,300	7.25	9.36	1,030,000	868,000	1.185	893,500	1.15
13	7—½" "	1.40	60.62	29,000	27,500	.111	54,100	5.75	9.91	751,000	770,000	.975	800,500	.94
20	5—⅝" "	1.00	60.75	20,900	20,000	.132	65,200	5.50	10.00	652,000	580,000	1.165	593,500	1.10
2	5—½" "	1.00	60.75	20,800	19,000	.119	58,800	4.75	10.27	604,000	532,000	1.135	565,500	1.07
7	3—½" "	.60	60.5	14,000	13,000	.1175	58,300	3.75	10.64	372,000	364,000	1.02	401,000	.925
3	3—½" "	.60	60.75	14,000	12,000	.1065	52,600	3.63	10.68	336,000	336,000	1.00	373,000	.90

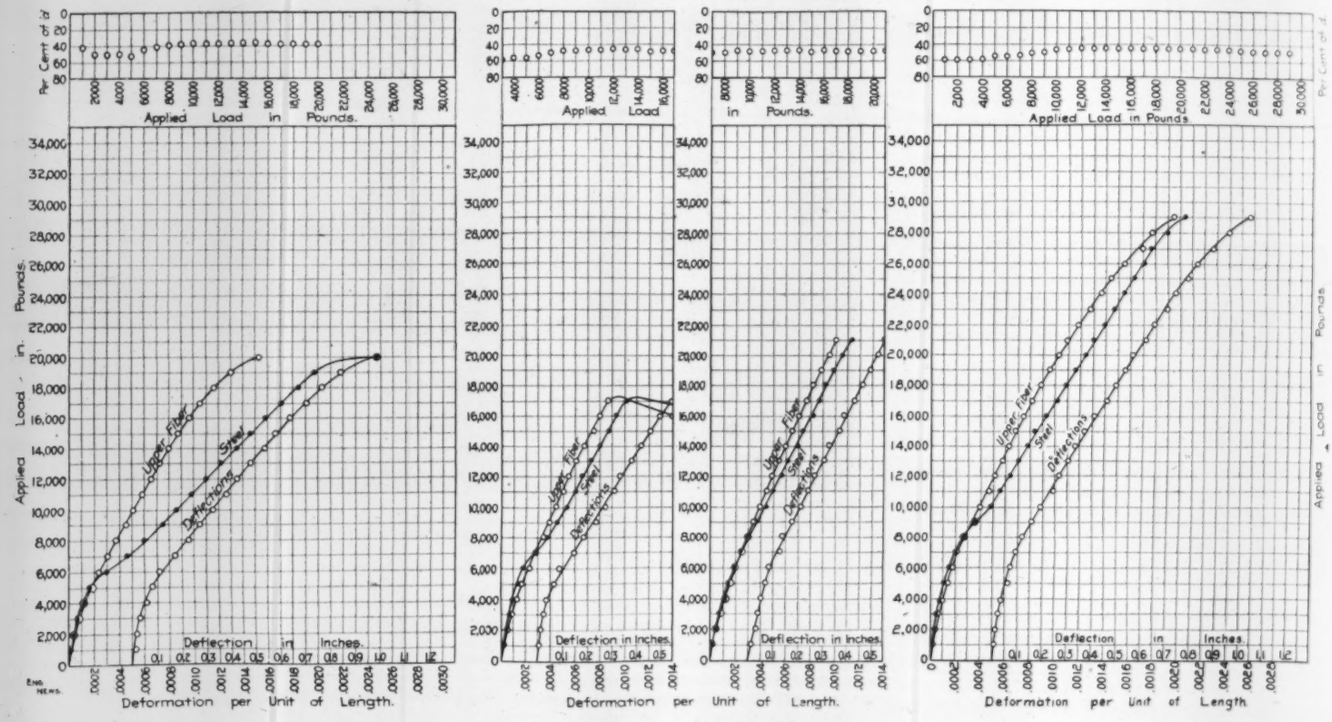
the beam after the steel has stretched considerably beyond its yield point. The diagrams of beams 14, 16, 17 and 19 show deformations beyond the maximum load. The exception to the above is in beams having more than 1% of metal of 55,000 lbs. per sq. in. elastic limit or more than 1½% of 33,000 lbs. elastic limit. In such beams the concrete at the top of the beam fails by crushing before the elastic limit of the steel is reached. In all the other beams the full compressive strength of the concrete was not developed at the maximum load. It may be noted that the deflection curve does not change its character until after the crook of the deformation diagram is well begun, and until after the yield point of the metal is passed, a result to be expected.

MAXIMUM LOAD AT YIELD POINT OF METAL.—The observed deformations show that for beams not having an excess of metal (say not more than 1% reinforcement with steel of 55,000 lbs. per sq. in. elastic limit nor more than 1½% with steel of 33,000 lbs. per sq. in. elastic limit for the concrete used in this work) the maximum load is nearly reached when the steel is stressed up to its yield point, and the load at the yield point of the metal may properly be taken as the ultimate strength of the beam. Actually, the maximum load is somewhat

STRESSES IN SECOND AND THIRD STAGE.—Several interesting characteristics are apparent in the second and third stage. In the steel diagram the crook or elbow of the second stage and the reversal of curvature just after are characteristic. The increased elongation of the steel just after the crook seems to indicate that the concrete has broken in tension through a part of the depth of the beam, and that a part of the weight of the beam which had been taken by the tension in the concrete has now been transferred to make added tension in the steel. A line parallel to the load-deformation line above the elbow and tangent to the elbow lies above this line a distance equal to the amount of added load which may be expected from the beam. It is quite noticeable that during the third stage the load-deformation diagram is a straight line, and that the increment of stress in the steel calculated in the assumption heretofore made, and hence its moment, is proportional to the increment of the load, though the stress in the steel is not proportional to the load. In fact, as may be seen by a study of the results, this increment in the resisting moment of the steel about the assumed centroid of compressive stresses is greater than the increment of bending moment of load; and in general for loads less than the maximum this re-

vertical distance between contact points of the second set was made 6 ins. Readings with the two pairs of extensometers were taken simultaneously as the loading of the beam progressed. From these observations two sets of values of the elongation of the steel and compression of the concrete were determined and also the resulting positions of the neutral surface. The results agree closely perhaps as closely as the variations in the transmission of the interior deformation to the contact point could be expected to give. It should be noted that this agreement does not hold for load under 3,000 lbs. In general, however, the neutral axis as determined by one pair of extensometers is a uniform distance below that determined by the other pair, the average variation above the elbow of the curve being 0.27 in. for beam No. 22 and 0.12 in. for beam No. 27. It should be noted that the measurements were made with an arrangement of loading in which the vertical shear is nearly zero between gage points and hence that there was little to cause distortion of section.

POSITION OF NEUTRAL AXIS.—The successive positions of the neutral axis as determined for the various beams are shown on the diagrams. In general, the neutral axis may be said to rise during the second or read-



Beam 2; Five ½-in. Johnson Bars; 0.69% Reinforcement; Maximum Load, 20,600 lbs.

Beam 14; Four ½-in. Kahn Bars; 1.11% Reinforcement; Maximum Load, 17,200 lbs.

Beam 4; Five ½-in. Kahn Bars; 1.39% Reinforcement; Maximum Load, 23,000 lbs.

Beam 13; Seven ½-in. Johnson Bars; 0.97% Reinforcement; Maximum Load, 29,000 lbs.

DIAGRAM SHOWING DEFORMATION, DEFLECTION AND ALTERATION OF NEUTRAL AXIS IN REINFORCED CONCRETE BEAMS, 2, 4, 13 AND 14 TESTED AT THE UNIVERSITY OF ILLINOIS.

(d is the Distance from Top of Beam to Center of Steel.)

greater than this, averaging about 6% more for all the beams and in one case reaching 15% more than the load at the yield point of the metal. The table shows that for the points chosen, which are just below the yield point of the metal and somewhat below the maximum load, the resisting moment for the steel (calculated by multiplying the stress found in the steel by the distance to an assumed centroid of the compressive stresses of the concrete and thus taking into account an equal amount of compression) is in general approximately equal to the bending moment due to the load and hence that the moment of the tensile stresses of the concrete is negligible. The exceptions to this are (1) in beam with light reinforcement and low elastic limit metal, in which case the moment of tensile stresses in the concrete may possibly account for the deficiency in the calculated resisting moment; and (2) in beams with an excess of metal, in which case the centroid of the compressive stresses, after the stresses approach the ultimate strength of the concrete, is probably lower than the position assumed, and hence the real moment will be less than the value here given. However, it seems that within the usual limits of reinforcement (say from ½% to 1½% reinforcement with steel of 33,000 lbs. per sq. in. elastic limit and to 1% with steel of 55,000 lbs. per sq. in. elastic limit for this concrete) the calculated moment of the steel about the centroid of the compressive stresses is for the maximum load approximately equivalent to the bending moment, and no consideration need be made of tension in the concrete.

sisting moment of the steel is considerably less than the bending moment. It is also found that for a load of 10,000 lbs. the total stress in the steel is approximately the same in all the beams (about 24,000 lbs.), although there is a difference in area of the steel and a slight difference in position of the neutral axis found for these beams. There is a similar uniformity at 15,000 lbs. and at 20,000 lbs. load for beams carrying such loads, the total stresses in the steel being about 42,000 and 64,000 lbs., respectively. The cause of the rectilinear form of the load-deformation diagram and the source of the resisting moment to make the deficit is yet to be investigated.

CONSERVATION OF PLANE SECTION.—Some doubt has been expressed concerning the correctness of the time honored hypothesis that a plane section before bending remains a plane section after bending, and the high results of tests of a special form of reinforcement made by loading with bars and brick has been cited in proof of the fallacy of this principle. To check its correctness, two extensometer devices were used on one side of the beam, the gage length being made the same in both cases by alternating the frames. One device had its contact points placed 11 ins. apart vertically as usual, 1¼ ins. below the top of the beam and 1¼ ins. above the bottom. In the other the upper points were applied at the usual position, 1¼ ins. below the top of the beam, and the lower points were applied 8½ ins. below the upper points. In another beam the

justment stage and then to remain in one position during the third stage until the maximum load is reached. For part of the beams the position of the neutral axis beyond the maximum load is shown, this position being higher than at the maximum load. The neutral axis is lower than is given by several theories which have been proposed. The positions of the neutral axis during the third stage in beams with different forms of reinforcement agree fairly well with each other, as is shown by the diagram where the change of neutral axis with the amount of reinforcement is apparent. The writer has not been able to give much study to this phase of the matter, but the line $k = 0.26 + 0.18\ p$ gives the position somewhat accurately, where k is the proportional depth of the neutral surface and p is the number of per cent. of the steel area, the depth from the top of the beam to the center of the steel being used in both cases. Theoretical considerations indicate that the locus of the neutral axis should be a curved line, but its deviation from a straight line within the usual limits of reinforcement will be slight.

VALUE OF MOMENT OF RESISTANCE.—It is no part of this paper to discuss formulas for strength of beams, but the equation given for position of neutral axis and the conditions found for maximum load suggest a method of calculation. The methods usually followed involve a calculation of the compressive stress in the upper fiber. The relation between deformation and stress in concrete is not definitely known and is probably variable. If it

an be determined experimentally or otherwise that a ertain per cent. of reinforcement is required to develop the full compressive strength for a given grade of concrete, then for a smaller area of reinforcement the value of the compressive stress at the upper fiber need not be considered in the calculations. For beams and loadings where other considerations do not govern, the resisting moment may be found by multiplying the total stress in the steel by the distance to the centroid of the compressive stresses. If the condition herein shown, that a load only slightly less than the maximum load for the beam obtains when the steel is stressed to its yield point, the elastic limit of the metal may be used for finding the ultimate strength of the beam. For the position of the neutral axis given above, the following equation for the value of the resisting moment of a rectangular beam would result, neglecting any tensile strength of the concrete,

$$M = (0.9 - \frac{1}{15} p) A S d,$$

where p is the number of per cent. which the area of the steel reinforcement is of the area of the cross-section of the beam counting down to the middle of the steel, A is the area of the steel, S is the stress per unit of area in the steel, and d is the distance from the top of beam to the center of the steel. For 1% reinforcement this would become 5-6 A S d and for 1½% reinforcement 0.8 A S d. For the concrete in the beams of this investigation the equations would hold if the reinforcement were not more than 1% with metal of an elastic limit of 55,000 lbs. per sq. in. and not more than 1½% with metal of an elastic limit of 33,000 lbs. per sq. in. An investigation of the limit of reinforcement for concrete beams of quite a range of mixtures and strengths would be of service, and also the determination of the position of the neutral axis with such concretes and for other shapes than rectangular. The writer believes that investigations along such lines will give the best basis for calculations of the strength of reinforced concrete beams.

COMPRESSIVE STRESSES.—Little can be said here concerning the compressive stresses in the concrete except to call attention again to the fact that the full compressive strength was not developed even with concrete considered by many to be too lean, except in the case of beams having a large area of metal. It would seem almost that the ordinary formulas give a larger compressive stress at the remotest fiber than actually exists there. The relation between stress and deformation near the crushing strength of concrete is probably different from that assumed in such formulas.

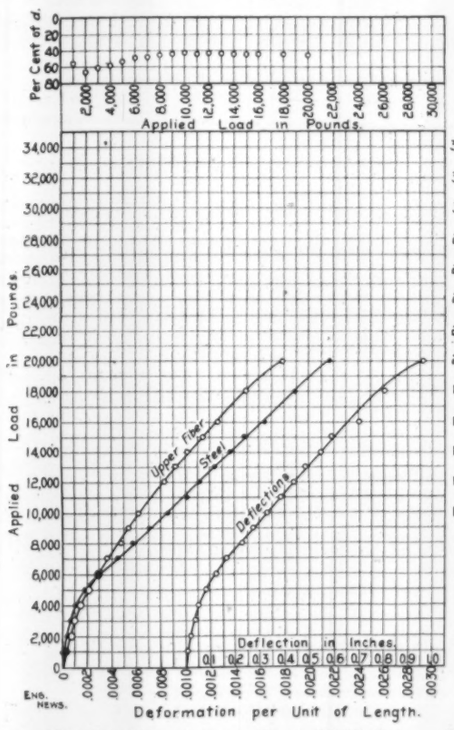
SHEAR AND ADHESION.—It had been anticipated that some of these beams, particularly those having a large area of reinforcement, might fail by shearing or more strictly by diagonal tensile stresses induced by shear. As a means of counteracting this, a portion of the bars in beams with 1 sq. in. metal or more were bent upward outside the one-third points of the beam and inclined diagonally to points about 4 ins. below the top at the ends. The Kahn bars of course were not treated in this way. In no case was there a crack or failure of the kind usually attributed to shear. Whether such failure would have occurred with the bars continued horizontally to the end cannot be told.

There was no indication of slipping of the rods in the concrete even with plain rods. A series of tests made to determine the adhesive bond between plain rods and concrete gave for the size of rods used an average of 300 lbs. per sq. in. of surface of steel. For beams of the dimensions and method of loading used, this would indicate for the two sizes used a factor of safety against slipping of 2½ to 4 when the steel is stressed to 33,000 lbs. per sq. in. and of 1¾ to 2½ for steel of 50,000 lbs. elastic limit when stressed to its elastic limit. For these beams, then, there is an ample margin against slipping.

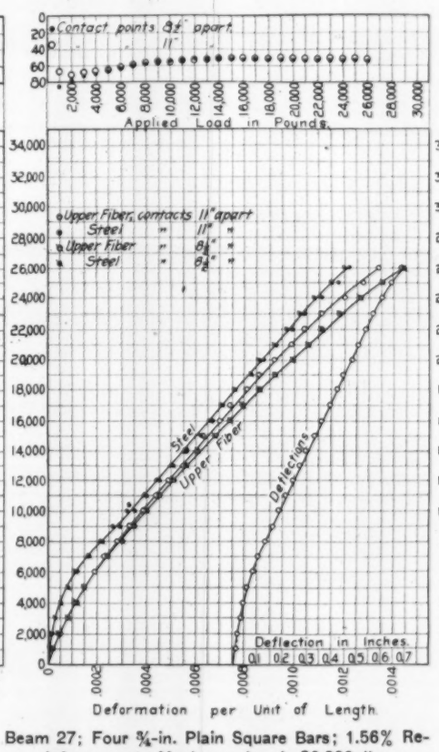
PLAIN CONCRETE.—A diagram of Beam No. 11 gives the load-deformation diagram for a plain concrete beam. The deformations are given for top and bottom fiber, the beam being 15 ft. 4 ins. long, 12 ins. wide and 13½ ins. deep and loaded as were the reinforced beams. It will be seen that the neutral axis is very close to the middle of the depth of the beam. This would indicate that for this beam the coefficient of elasticity of concrete for tension and that for compression are approximately equal.

OTHER TESTS.—Among tests made in connection with those described were a series of tests on plain concrete beams, tension, compression, and shearing tests of concrete cylinders to determine relation between deformation and stress, and tension tests of reinforced concrete. The tests to determine the relation between stress and deformation were not complete enough to base conclusions upon. Tests were also made on reinforced concrete beams by taking off the load at two or more loads and noting the deformations as the load was being removed and again put on.

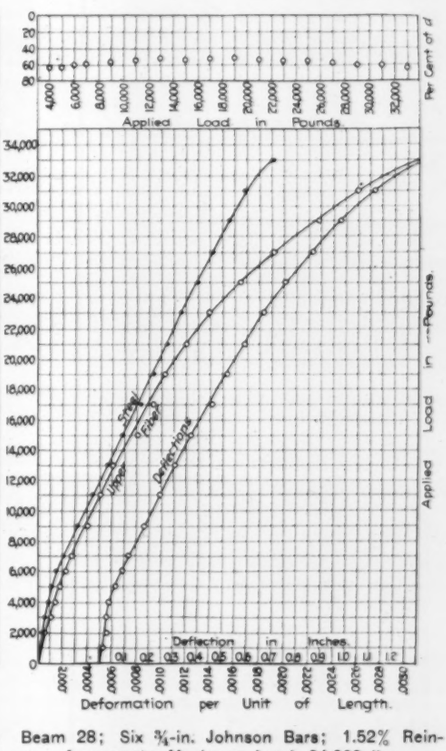
CONCLUSION.—It was found necessary by reason of limitations of floor space to reduce the number of beams for the several kinds and amounts of reinforcement below what was planned, and extensometer measurements were not obtained on three of the beams tested. However, the deflections and maximum loads of these three beams checked those of their mates very closely, and the general action and behavior of all the beams were so similar and uniform that the writer is disposed to place more reliance on the results of individual beams than he generally does in experimental work, and particularly more than can be placed on small concrete beams. While general conclusions are not to be drawn hastily or on slight evidence, the following deductions seem warranted for the beams and loading under consideration. (1) The composite structure acts as a true combination of steel and concrete in flexure during the first or preliminary stage, and this stage lasts until the steel is stressed to, say, 3,000 to 4,000 lbs. per sq. in., and the lower surface of the concrete is elongated $\frac{1}{10,000}$ to $\frac{1}{7,500}$ of its length. (2) During the second or readjustment stage there is a marked change in distribution of stresses, the neutral axis rises, the concrete loses part of its tensional value, and tensile stresses formerly taken by the concrete are transferred to the steel. During this stage minute cracks probably exist, quite well distributed and not easily detected. (3) In the third or straight-line stage the neutral axis remains nearly stationary in position and the concrete gradually loses more of its tensional value. Visible cracks appear and gradually grow larger, though no change in the character of the load-deformation diagram results. (4) In beams with the metal reinforcement small enough in amount not to develop the full compressive strength of the concrete, the maximum load is reached or nearly reached when the metal is stretched to its yield point, and the tensional value of the concrete is here negligible except with light reinforcement, and the load at the yield point of the metal may well be considered the full strength of the beam. The later crushing of the concrete at a smaller load is the effect of the rapid stretch of the steel. (5) So far as strength of the beam is concerned, the load when the steel is stressed to its elastic limit seems the proper basis for the factor of safety and working load. (6) So far as strength of beam is concerned, steel having a high elastic limit is advantageous, it being assumed that there is sufficient provision against the slipping of rods and shearing failures. (7) The determination of the limit of reinforcement which may properly be used with different mixtures and grades of concrete may best be decided by experiments on beams made to determine this. For the 1—3—6 concrete used, reinforcement as high as 1½% for steel of 33,000 lbs. per sq. in. elastic limit and 1% for steel of 55,000 lbs. per sq. in. elastic limit may be used without developing the full compressive strength of the concrete. (8) With those beams having sufficient metal to develop the full compression strength of the concrete, the calculated resisting moment of the steel and concrete is in excess of the applied bending moment, which indicates perhaps that the center of gravity of the compressive stresses is much lower than when the compressive stress is well below this limit. (9) There was no marked difference in results found for the different forms of reinforcing bars used. It is assumed here that the beams are subject to simple flexure and that provision is made against shearing stresses and slipping of bars. The assumption that incased steel acts with the same co-



Beam 20; Five ¼-in. Johnson Bars; 0.69% Reinforcement; Maximum Load, 20,900 lbs.



Beam 27; Four ¾-in. Plain Square Bars; 1.56% Reinforcement; Maximum Load, 26,900 lbs.



Beam 28; Six ¾-in. Johnson Bars; 1.52% Reinforcement; Maximum Load, 34,300 lbs.

DIAGRAM SHOWING DEFORMATION, DEFLECTION AND ALTERATION OF NEUTRAL AXIS FOR REINFORCED CONCRETE BEAMS 20, 27 AND 28, TESTED AT THE UNIVERSITY OF ILLINOIS.

(d is the Distance from Top of Beam to Center of Steel.)

efficient of elasticity as naked steel has not been established and may not be true. However, the yield point of the metal is closely shown by the load-deformation curves. It should be added that experiments like those here described show the necessity for a full experimental investigation of reinforced concrete.

The University of Illinois purposes issuing a bulletin giving the results of these tests in detail, and plans are being made for extending the investigation. It should be said that the work of making these tests was done principally as thesis work, and that Messrs. R. V. Engstrom, F. E. Mills, S. D. Brown and R. J. Blackburn of the class of 1904 are entitled to credit for the care, thoroughness, and untiring interest given to the investigation and are to be commended for their skill and thoughtfulness.

A REVIEW OF THE ENGINEERING EXHIBITS AT THE ST. LOUIS EXHIBITION.

The engineering profession, in all its varied branches, is well represented at the St. Louis exhibition. In fact, a general inspection shows that it is represented in all the main buildings and in some of the minor buildings, to say nothing of the outdoor exhibits. It is in some respects unfortunate that the engineering exhibits are not more consistently grouped and classified; for instance, there are exhibits of gas machinery and appliances in three of the buildings, besides an outdoor exhibit. But the difficulties in obtaining exhibits and in distributing the available space among exhibits entered at different times, undoubtedly accounts to a large extent for this peculiarity. We cannot now go into the details of the exhibits, some of which have already been described, while others will form the subject of future articles. But the general inspection above referred to shows such a great number and so wide a range of engineering exhibits that we present here a general review for the benefit of our readers. These exhibits enter even into the Art Building, where we find some paintings of railways and bridges, including a large canvas representing the erection of the steel work for the new East River Bridge, New York.

In general railway construction we find the great models of the new terminal stations in New York and Washington, and a number of American and foreign yard and terminal works, represented by plans, photographs and models. There are a great number of locomotives, including five of foreign construction, while drawings and photographs of locomotives abound. The actual locomotive exhibit includes the largest locomotive in the world (the Mallet compound of the Baltimore & Ohio Railway), and the smallest: the latter is one of the little engines used to operate the miniature railways at fairs, etc., one of which is now in operation at the exposition. There are also several electric locomotives for mining and industrial work, but no compressed air locomotives. These electric locomotives include the trolley, third-rail and storage battery systems. One of the most important and most striking features of the exhibition is the locomotive-testing plant of the Pennsylvania R. R., which is now in full operation and has been described in our columns. There are three handsome trains of passenger cars, one of which (exhibited by the Missouri Pacific Ry.) is equipped with automatic couplers for the air and brake hose. There are a number of steel freight cars, refrigerator, tank and ballast cars, and also dump cars for construction work; and a wrecking crane of 100 tons capacity. Wheels, bolsters, brakes, couplers and such auxiliaries are well represented; among them are cast steel frames, and the Schoen rolled steel wheels. Electric street and interurban cars are numerous, including a high-speed car on six-wheel trucks, which is somewhat of a novelty in interurban railway practice.

In railway track and track appliances the exhibits are rather meager, and the American exhibits are not of particular interest, if we except the collection of specimens and drawings of ancient and modern track in the historical locomotive collection of the Baltimore & Ohio Ry. Otherwise the display is much the same as at any convention of the roadmasters or maintenance of way associations. Some well-known rail joints, frog and switch work, tie plates, inspection cars, cattleguards, etc., pretty well fill the list. The English, French and Austrian railways show specimens of track, rail joints, etc., and drawings of track construction, and Japan shows rail sections from the billet to the finished rail. Signals and interlocking are but poorly represented, but Germany is a conspicuous exception to this general statement, having a large exhibit, which consists of three sections of double-track, with steel and treated timber ties. The tracks include switches and crossovers, and are equipped with two complete systems of signal apparatus for block, interlocking and station work. One of these is a manual-controlled system, and the other an electrical system. The exhibit represents German standard practice in track construction, stations, signal cabins, and all the details of signaling equipment.

Bridges and tunnels are represented by various models and drawings. The notable bridges include the Quebec cantilever bridge over the St. Lawrence, with a central span of 1,800 ft.; and the steel arch-truss bridge over the Zambesi River at the Victoria Falls, in South Africa. This bridge has a central span of 500 ft., with deck truss spans of 87½ and 62½ ft. from the arch to the abutments; it is a double-track structure, 420 ft. above the water, and is to be finished this year. The Scherzer and Cowing types of bascule bridges are represented. The French and German sections include views and drawings of the Paris and Berlin elevated railways, and the Langen elevated railway, with suspended cars. The Austrian building contains a model of the Isonzo masonry arch bridge of 262.4 ft. span, and also a model showing the various stages of tunneling under the Austrian system, with steel ribs for centers carrying a masonry lining. The Pennsylvania R. R. has a full-sized section of its Hudson River tunnel. Structural steel work of buildings is represented mainly by jail work, and a few examples of columns and column and beam connections. Concrete-steel construction is much more largely represented by about ten different systems, but unfortunately these are scattered through different buildings.

River and harbor work is largely represented, more especially in the foregoing sections, and the engineer interested in this class of work will be well repaid for time spent in studying the numerous machines and methods shown by models and large-scale drawings. Harbors and harbor works in all parts of the world are shown, and especially notable are the steam barges employed for depositing immense bags or mattresses of concrete for the substructure of piers and docks. France and Germany show river improvement works and canal traction, and work in this country is shown in the exhibits of the Chicago Sanitary District, the Mississippi River Commission, and the Engineer Corps of the U. S. Army. Numerous handsome models show ladder and suction dredges of various designs, American and foreign, but the dipper dredge seems not to be represented, although there is the Robinson steam shovel, described in our issue of Aug. 4.

Irrigation works in Arizona, in the Argentine Republic, in Mexico and in Egypt are represented, the last-named including a large relief map of the valley of the Nile, and details of the great Assouan dam and other works. Austria shows large models of a bridge weir, resembling the shut-off gates at Sault Ste Marie. Panels are hinged to the bottom of a through-truss bridge, and raised or lowered as required by a traveling hoist. Both France and Germany have exhibits in drainage engineering, the latter mainly in regard to the reclamation and cultivation of peat lands and the utilization of peat.

Steamships are represented by beautiful col-

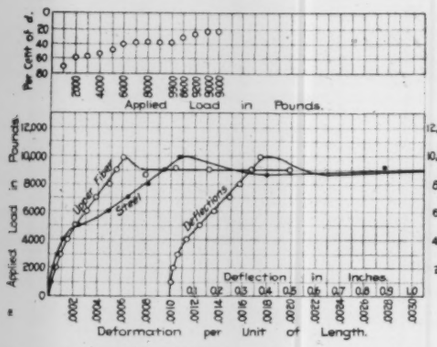
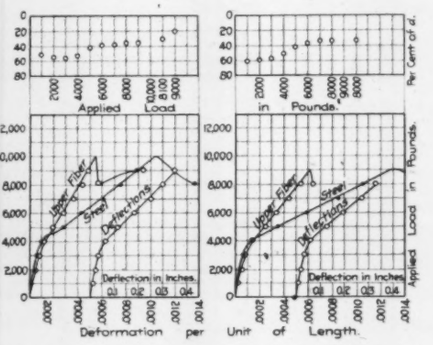


Diagram Showing Deformation, Deflection and Position of Neutral Axis in Beam 16.

(Three ½-in. Plain Square Bars; 0.52% Reinforcement; Maximum Load, 9,900 lbs.)



Beam 17; Three ½-in. Plain Square Bars; 0.52% Reinforcement; Maximum Load, 10,000 lbs.

Beam 21; Three ½-in. Plain Round Bars; 0.41% Reinforcement; Maximum Load, 9,000 lbs.

Diagrams Showing Deformation, Deflection and Positions of Neutral Axis in Beams 17 and 21 Tested at the University of Illinois.

(*d is the Distance from Top of Beam to Center of Steel.*)

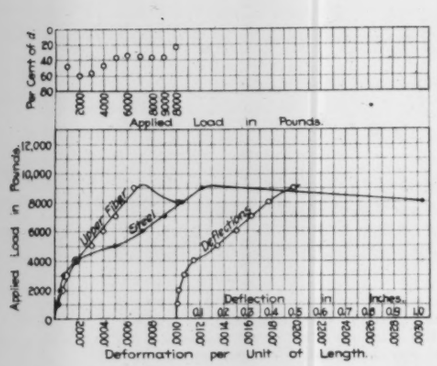


Diagram Showing Deflection, Deformation and Position of Neutral Axis in Beam 19.

(Three ½-in. Plain Round Bars; 0.41% Reinforcement; Maximum Load, 9,200 lbs.)

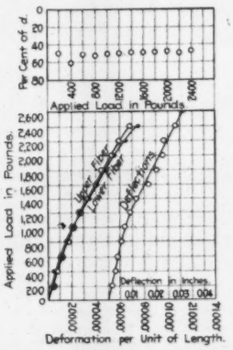


Diagram Showing Deformation, Deflection and Positions of Neutral Axis for Plain Concrete Beam 11 Tested at University of Illinois.

(Maximum Load, 2,600 lbs.)

sections of models of vessels of all kinds, from tug-boats and ice-breakers to the four new turbine steamers of the Cunard Line; these are of two types, one of which will have twin screws while the others will have four screws and a guaranteed speed of 25 knots. Warships are well represented, and the United States navy exhibit includes working models showing the methods of docking large vessels in dry docks and floating docks.

In the line of machinery, large space would be required merely to enumerate the various classes of work represented. Besides a large exhibit of metal-working and wood-working machines (many of the machine tools being electrically operated), there are numerous special processes. Automatic machines are shown at work making small screws and other fittings, six or more operations being effected by the one machine, which requires only to be supplied with the necessary stock bars. There are numerous looms in operation, box-making machines, printing and type-setting machines, a wire-drawing mill, a boot and shoe factory, a cotton spinning mill and a mint are in full operation. Crushers and rolls, cement mills and concentrating and classifying mills for ore treatment are largely represented. To the mechanical engineer and the machinist there is an endless source of interest, and exhibits of this kind are included in all the principal buildings. Power transmission and controlling apparatus are included, with the numerous machines and appliances incidental to the use of machinery for manufacturing purposes.

The power generating plant of the exhibition is a varied and comprehensive collection of engines of all kinds and sizes. The largest units are of 5,000 and 3,200 HP., and the others range down to 50 HP. and less. Steam, gas and oil engines; steam turbines (of four or five types) and impact water wheels are all included. On the larger engines, the Corliss type of valve and valve gear is most largely used, but in great variety of design; piston and slide valve engines are also represented, and in even greater variety. The boiler plant comprises various American and foreign makes of water-tube boilers, and there is a varied exhibit of auxiliaries in the way of condensers, air pumps, feed pumps, etc. Here, also, are a coal handling and conveying plant, and two gas producer systems. There are not many steam engine exhibits outside of the power plant, but the exhibit of gas engines is very large, including some fifteen different makes, each represented by engines of various sizes and for various purposes. There are little engines of 2 HP. for marine work, and others of 200 HP. and over. There are also three or four makes of oil engines.

Gas machinery is represented by three or four makes of gas producers, and by two special exhibits of machinery and apparatus, one by a single firm and the other a collective exhibit, arranged by the Western Gas Association. Acetylene gas is rather poorly represented. The electrical generation and application of power is, of course, very extensively represented, and includes all the main buildings; the telegraph and telephone, electric operation and control of machinery, electric lighting and heating, and various applications of electricity in the industrial arts are shown. Electro-chemical and electro-medical work are special branches, in both of which Germany has very elaborate and extensive exhibits. Engineering, surveying and drawing instruments and materials are represented by the exhibits of American and foreign manufacturers and by such departments as the lake, coast and geological surveys, and the engineering schools. The French and German sections include exhibits and reports relative to systems of precise leveling.

The automobiles are very conspicuous, as might be expected, and they occupy a good share of the space devoted to transportation. There are nearly sixty exhibitors, forty of whom are American and the others French and German. Both electric and gasoline cars are included, and there is a great variety in the mechanical design and construction. There is also a steam wagon, with Turgan-boiler, as illustrated in Engineering News July 28 (p. 80). Traction engines are represented by some large English machines, and a few smaller American machines; but there is a good display of road rollers and road-working machinery, street sprinklers and sweepers, and an oil sprinkler for sandy roads. The government exhibits also include machines for testing the properties of road-making materials. In sanitary and municipal engineering, the display is exceptionally large and varied. Methods of street cleaning and garbage disposal are shown, and the boards of health of various states and cities have individual exhibits illustrating their work. There is also a bacteriological laboratory in operation, and a large display of social and vital statistics. In engineering education, various institutions show their methods and equipment, their results, etc.

The model street is a point of special interest in this connection, though it is not as complete as its originators intended. The street itself comprises different styles of paving: brick, sheet asphalt, macadam of various kinds, and bituminous macadam, but there are unfortunately no signs explaining the different methods of construction. The principal features comprise the following: 1. New York Building. Here are models, photographs and drawings of the rapid transit subway, docks, street sections, public baths and buildings, garbage cremation and reduction plants, and the various dams, aqueducts, etc., of the water supply system, under the control of the Aqueduct Commission. There are samples of the carts and appliances of the street cleaning departments, and a working model of the garbage-sorting plant and crematory, which is explained by an employee of the department. 2. Municipal Museum; St. Paul and Minneapolis. This contains maps and models, reports of the municipal departments, and views and reports dealing with the successful work of the smoke inspection and sanitary departments. 3. Town Hall. This contains photographs and drawings of the city parks, subways, docks, etc., of Boston, and drawings of the water supply system exhibited by the Massachusetts Water Commission. The city of Philadelphia is represented by photographs, and a large vacant space is to be occupied by a Buffalo exhibit. There are also a Kansas City building and a San Francisco building, but these contain little of engineering interest. At one end are the Exposition emergency hospital and the children's playground and nursery. The other buildings on the street are a drug store and restaurants. In another part of the grounds, behind the Art Building, is a model country schoolhouse.

Mining and metallurgical engineering are well represented, both in natural and manufactured products, and in machinery and apparatus. Crushers, rolls, drills, magnetic separators, concentrating and stamp mills, conveyors, hoists, etc., are shown, and there are a number of very fine models of mining and metallurgical plants, together with laboratory equipment and apparatus. The outdoor mining exhibits comprise the following: 1, foundry; 2, pottery; 3, cement and reinforced concrete building; 4, mining railway; 5, well-drilling outfits; 6, coal mine and breaker; 7, three reduction mills for lead and gold ores; 8, a gas producer plant; 9, a wire tramway or cableway; 10, a metallurgical laboratory; 11, a timber treating and testing plant.

The United States Government has a large building, in which every department and bureau are represented, and these include much matter of engineering interest in connection with the work of the coast and geological surveys, the irrigation investigations, river and harbor work, pneumatic mail dispatch, coin and cartridge-making machinery, etc.

From what has been said it will be evident that engineering and the work of the engineer are well represented, both in regard to American and foreign practice. In fact, to the young engineer who can spend a few days at the exhibition a study of the exhibits in this department may be made of great educational value. He will find many great works represented, with the methods and machinery employed, and he may acquire a mass of practical information which he could obtain in no other way.

THE CONSTITUTION OF PORTLAND CEMENT FROM A PHYSICO CHEMICAL STANDPOINT.*

By Clifford Richardson.†

A vast amount of time and energy has been devoted to attempts to elucidate the constitution of Portland cement, but with how little success may be seen from a review of the literature of the subject which has been prepared by the writer and published in Vols. 4 and 5 of "Cement," Progress Publishing Co., 21 Park Row, New York. A glance at this review will show that the conclusions arrived at have been based, as a rule, on little more than theory.

The determination by Le Chatelier and Törnebohm, with the aid of the microscope and petrographic methods, of the optical characteristics of the mineralogical entities which constitute a Portland cement clinker, the work of Le Chatelier and of the Newberrys in preparing synthetically the silicates and aluminates which might possibly exist in the clinker and of the Newberrys in the preparation of clinker in molecular proportions from pure chemicals, are noteworthy exceptions and their results, confirmed in several instances by others, are of great value.

For the study of clinker by microscopic methods it is necessary to prepare sections which shall be so thin as to be transparent. This is readily done by grinding down a suitable fragment on one side until it is flat, polishing this, then mounting it with balsam on a piece of glass and grinding down the other side of the fragment until a thickness is reached which permits the transmission of light. The section thus prepared is mounted under a cover glass and is ready for observation.

It is a peculiarity of minerals of crystalline structure that they vary in their optical properties according to the system in which they crystallize and especially in regard to their behavior towards polarized light. It will be impossible here to go in detail into an explanation of the phenomenon, but it is sufficient to say that different minerals can be differentiated and recognized by their greater or smaller optical activity. The methods are the same as those which are used by geologists and petrographers in the study of our crystalline rocks.

By this method of study Le Chatelier, and, at the same time independently of him, Törnebohm identified in Portland cement clinker four distinct mineral constituents which Törnebohm described as follows, naming them Alit, Belit, Celit and Felit.

Alit is the predonderating element and consists of colorless crystals of rather strong refractive power, but of weak double refraction. By this he means that alit in polarized light between crossed nicol prisms has insufficient optical activity to produce more than weak bluish gray interference colors.

Celit is recognized by its deep color, brownish orange. It fills the interstices between the other constituents, being the magma or liquid of lowest freezing point out of which the alit is separated. It is strongly double refractive, that is to say, gives brilliant colors when examined between crossed nicol prisms.

Belit is recognized by its dirty green and somewhat muddy color and by its brilliant interference colors. It is bi-axial and of high index of refraction. It forms small round grains of no recognized crystalline character.

Felit is colorless. Its index of refraction is nearly the same as that of belit and it is strongly double refractive. It occurs in the form of round grains, often in elongated form, but without crystalline outline. Felit may be entirely wanting.

Besides these minerals an amorphous isotropic mass was detected by Törnebohm and Le Chatelier. It is called isotropic because it has no effect upon polarized light. It has a very high refractive index.

Törnebohm adds the important fact that a cement 4% richer in lime than usual consists almost entirely of alit and celit.

The preparation of synthetic silicates and aluminates which might exist in Portland cement was carried out to a certain extent by Le Chatelier and the Newberrys, but in neither case were they characterized completely, especially as to their optical properties. This has been done by the writer within the last two years, and the optical properties and other characteristics of the following definite silicates and aluminates have been determined.

Mono-calcic silicate—SiO_2 CaO: A crystalline substance of high optical activity and little or no hydraulic properties. Specific gravity 2.90.

Di-calcic silicate—SiO_2 2CaO, or more probably $2SiO_2$ 4CaO: A definite crystalline compound of high optical activity and of very little hydraulic activity except in the presence of carbonic acid, but setting slowly in water, generally lacking volume constancy. Specific gravity 3.29.

Tri-calcic silicate—SiO_2 3CaO: A definite crystalline silicate of low optical activity and corresponding in this respect with alit. Its hydraulic activity is not great, but greater than that of di-calcic silicate. If fused and re-

*An address before the Association of Portland Cement manufacturers at Atlantic City, June 15, 1904.

†New York Testing Laboratory, Long Island City, N. Y.

ground it sets slowly like Portland cement. Specific gravity 3.03.

Three definite silicates of calcium, therefore, appear to exist, the two more basic ones being strongly differentiated from each other by their optical activity.

Mono-calcic aluminate—Al_2O_3 CaO: This aluminate is a crystalline substance of high optical activity, but it is not sufficiently basic to permit of its existence in a material of such basic character as Portland cement clinker. Specific gravity 2.90.

Tri-calcic di-aluminate—$2Al_2O_3$ 3CaO: This aluminate is one of highly crystalline character and of great optical activity, making it readily recognizable. Specific gravity 2.92.

Di-calcic aluminate—Al_2O_3 2CaO: A substance crystallizing from a state of fusion in dendritic forms having no optical activity and being, therefore, isotropic. This differentiates this aluminate very sharply from the preceding one and makes the identification of the two materials very easy. Specific gravity 2.79.

Tri-calcic aluminate—Al_2O_3 3CaO: This aluminate crystallizes from the fused condition in elongated octahedra. It is isotropic and it might at first be assumed that it was not a definite compound, but merely the di-calcic aluminate crystallizing out of a magma of indefinite composition. It has been shown, however, by further investigations too lengthy to go into at this point to be undoubtedly a definite aluminate. Specific gravity 2.91.

Definite compounds of iron and lime and alumina and magnesia have also been shown to exist, but their consideration here is unnecessary as the constitution of Portland cement can be better discussed, theoretically, by a study of clinker into which these elements do not enter.

Among the theories advanced as to the constitution of Portland cement there are those which assume the presence of certain so-called silico aluminates, such as $2SiO_2$ $2Al_2O_3$ 6CaO and others of less basic form. All of these proposed compounds have been prepared by the writer and found not to be definite chemical compounds nor to correspond in any way with any of the mineral entities found in industrial clinker. They are in fact only solid solutions, of aluminates in silicates, of indefinite structure.

This brings us to the point where the nature of a solution, especially of solid solutions, must be taken up.

SOLUTIONS.

Solutions may be defined as the merging of two or more substances in one another in such a way that it is impossible to recognize them by any physical means. In this respect they differ from the elements and definite chemical compounds. The elements cannot be or have not been differentiated by any chemical or physical means into other substances. Definite chemical compounds can be differentiated by chemical means into their constituent elements, but at the same time are always composed of these elements in a definite mathematical ratio, involving only whole numbers and depending upon the combining weight of each element.

Mixtures of gases, gases dissolved in liquids, liquids which are mixed together and salts dissolved in liquids are types of solutions. In the preceding paragraph mention has been made of solid solutions. We owe our conception of such solutions to Van't Hoff, a Dutch chemist, who, in 1880, having observed some abnormal features in the behavior of certain solutions of solids in liquids when they were frozen, was led to believe that the solid which separates on freezing is not the pure solvent, but a mixture of the solid solvent and the dissolved substance forming a solid solution. Investigations have proved that the conception was justified. Roozeboom has shown from a study of mixtures of fused salts that on cooling solid solutions are often formed, especially if the salts have the same crystalline form and habit.

The constitution of our igneous rocks may best be explained by considering them as solid solutions, which, when the original liquid magma, from which they are derived, is cooled to a temperature at which freezing sets in, are formed by the crystallization of such mineral species as the constitution of the magma may permit, and which we recognize as quartz, mica, felspar, etc., the composition of which while in approximately definite proportions is more or less modified by the substances which they may retain in solution.

The structures of alloys has also been most satisfactorily explained by considering that different metals are soluble in each other in different proportions under different states of concentration and at different temperatures; that of steel has been especially thoroughly worked out in the same way, and it has been shown that it consists of a solid solution of carbon in pure iron, while that of cast iron is explained by the fact that the amount of carbon soluble in the molten iron is so great that a portion separates out, as graphite, on cooling.

Another type of solid solution is glass. In this material we have a solid solution of silica, lime and alkalies, in indefinite proportions, in which none of the constituents can be detected, and out of which nothing separates on freezing. This is regarded as a homogeneous solid solution and corresponds closely to a homogeneous liquid solution. In some mixtures of fused salts and in some of the alloys we have heterogeneous solid solutions as more than one solid solution may separate on freezing. Such a separation is due to what is known as selective freezing. This is well illustrated by the freezing of a solution of salt in water. That portion of the solvent which becomes solid first contains less salt than anything subsequently separated. If we take a 15% solution of salt in water as an example, as has been done by Howe in his excellent book entitled "Iron, Steel and Other Alloys," to which the reader is referred for an exhaustive explanation of the theory of solid solutions, and to which the writer is much indebted, it will be found that the solid matter that first freezes out is nearly pure water, and that there is a corresponding increase in the concentration of the mother liquor. The solid which subsequently separates will contain progressively more and more salt in solid solution in the ice, and there will be a progressive fall in the freezing point of this liquid, until when the temperature has reached minus 22° C. and the proportions of salt in the mother liquor is 23.6%, further concentration will not occur and the two elements, water and salt, solidify without selection and form what is called a eutectic. The freezing point remains constant at 22° C. until the entire material is solid. The solid originating in this way is a mixed mass of crystals of water and of salt inter-stratified, the salt forming 23.6% of it and ice 76.4%. The same result would happen with a 20% solution of salt, the selective freezing going on until the concentration of 23.6% had been obtained and the eutectic ratio had been reached. If the original solution contained 23.6% of salt it would not freeze until a temperature of minus 22° C. had been reached, and then it would all become one uniform mixed mass of the solid known as the eutectic. If the percentage of salt is greater than the eutectic ratio, 23.6%, then the material which first freezes will be salt containing some water in solution and the concentration in relation to salt would be reduced until the eutectic ratio is reached. That is to say, the composition of the eutectic is constant, no matter what the initial ratio between the solvent and that which it dissolves is. Many alloys are quite parallel in their constitution to that of the solid salt water series. Tin and lead form a eutectic constituting 31% of tin and 69% of lead of constant freezing point. Any tin-lead alloy of other than the eutectic proportion will consist of lead with tin in solution and the eutectic, or tin with some lead in solution and the eutectic, in accordance with whether the lead or tin are in excess over the eutectic ratio.

In some cases, however, where metals or salts are not mutually soluble in the solid state, unselective freezing may take place, that is to say, the elements of the fused solution may solidify separately, and this may be regarded as a eutectiferous mixture.

The term eutectic means well melting, because the eutectic is usually the material which freezes out at the lowest temperature, no matter what the proportions may be of which the mixture may happen to consist.

Two salts which crystallize in the same form may separate from aqueous solutions in such a crystalline form containing more or less of both substances, depending upon the concentration, and in the same way a crystal consisting entirely of one salt may be built up with another by immersing it in a solution of a so-called isomorphous salt of proper concentration, that is to say, of a salt which crystallizes in the same form. These crystals are known as isomorphous mixtures or mixed crystals. Exceptionally a substance which crystallizes in a different form from another may assume the form of the latter and crystallize with it as a so-called isodimorphous mixture or solid solution. The salt which has changed its form must, of course, be under a certain tension in such a solution. Such a state of affairs will be found to be the case in a Portland cement clinker, and an example of such an isodimorphous mixture among simple well-known salts will be instructive. The orthorhombic sulphate of magnesia, $MgSO_4$. $7H_2O$, for instance, can take up and hold in solution in the form of orthorhombic crystals as much as 18.78% of the monoclinic ferrous sulphate, Fe_2SO_4. $7H_2O$, while the iron salt can take up 46.00% of the magnesia sulphate and hold it in solution in the monoclinic form. Between these limits we find both forms of solid solutions or crystals present. The relation of the isotropic aluminates of lime to the anisotropic silicates will be found to be, in Portland cement clinker, similar to that which has been described.

The relation of materials to each other which are not soluble or miscible with each other in all proportions may be also illustrated by mixtures of ether and water. In such mixtures, if they are shaken and the amount of either present is not greater than what the water can dissolve, a homogeneous solution is formed. As soon as the proportion of ether reaches a point where it will not dissolve on shaking, an emulsion will form and this will continue to be the case with the increase in the proportion of ether until the latter reaches an amount where it can dissolve the water present. If it were possible to cool ether-water mixtures so rapidly as to solidify them at once we should find, for certain concentrations, where the ether was only slightly in excess of what could dissolve, a solid solution of water and ether and an emulsion of water and ether corresponding in structure to a eutectic, but here the eutectic would not consist of separate particles of ether and of water, but of separate particles of ether saturated with water and water saturated with ether. This is a structure which will be met with in Portland cement clinker. Whether it is a eutectic or not is unimportant. It is the structure itself which is illustrative of what takes place when the components of the mixture are not soluble in each other in all proportions. In Portland cement clinker of certain concentrations similar emulsions are found.

It will be of interest here to consider a solution which bears some parallel to those which we are about to consider in Portland cement. Steel is a solution of carbon in pure iron. Carbon dissolves in the molten iron to a very considerable extent and remains in solution as long as the metal is molten. If cooling and freezing takes place, the structure of the solid metal will be found to depend upon the proportion of carbon which was dissolved in the original iron and the temperature at which it was cooled. If carbon amounts to but a few hundredths of 1% the solid metal will be wrought iron; if it does not exceed that amount which will remain in solution in iron after cooling it is steel; if the carbon is greater than this some of it will separate as graphite, and the solid metal will be cast iron. The structure of the metal in the solid state under these different conditions may be determined with the microscope, but, of course, not in thin sections as in the case of clinker, but by the examination of polished surfaces which have been etched in some appropriate way. The study of iron and steel by these methods has been carried out most elaborately and books published on the subject. The writer has already referred to one by Prof. H. M. Howe, of Columbia University, entitled "Iron, Steel and other Alloys," in which the metallography of steel is considered and discussed at length. It will only be necessary to state here in a general way that when molten iron containing carbon in solution, in amount insufficient to cause a separation of graphite on cooling, is rapidly cooled from a very high temperature, the solid metal will be found to have definite properties, depending on the percentage of carbon present, the lower percentages furnishing mild steel, the higher tool steel with a structure which is so definite that it has been named austenite. It will be also found that when the steel in this condition is re-heated, as in tempering, the austenite structure is lost, the metal being transformed into a material of quite a different structure with resulting changes in its physical properties.

The possibility that Portland cement might be, in a parallel way to steel, a solution of some aluminate in a tri-calcic silicate was evident in the early stages of the writer's investigations, and the problem at once became the solution of the questions, what is alit and what is celit, the two essential constituents of a clinker. If they are solid solutions, what are the components of each, and is their structure changed like that of steel at a definite temperature?

The problem was approached in the following manner: Clinkers were made from pure chemicals, silica, alumina and lime, in the proportions found in industrial clinker. In order to obtain these proportions it was necessary to determine what the molecular ratios between silica, alumina and its chemical equivalent iron oxide, and lime and its chemical equivalents the magnesia and alkalies were. Fortunately there are in existence two very exact analyses of industrial clinker which will serve for this purpose. If, in these analyses, the weight per cent. of each constituent is divided by the molecular weight of this constituent, that is to say, by its combining number, the quotient will give the relative number of molecules of the different substances in the clinker. It is also possible by adding the molecular proportions of alumina and iron together and of all the bases together to discover the relation of silica, alumina and iron oxides, these being known as R_2O_3 bases, but here acting as acids, and the lime and other bases, known as the MO bases, to each other and by dividing each of these ratios by such a figure as will make that for silica equal to 1.0 to express this still more simply. It is also possible from these ratios to calculate by multiplying them by the atomic weight of silica alumina and lime the proportions by weight and the percentages of each of these materials which it is necessary to use in order to produce a pure clinker having the same basicity and molecular ratio as the industrial clinker, but in which the unessential elements are absent. In this process, however, it is necessary to deduct the amount of lime which is present in combination with sulphuric acid as this plays no part in the formation of the clinker.

The molecular ratios for the two cements which have been mentioned appear in the following table, together with the percentage composition of the pure clinkers which were made in these proportions, calculating the R_2O_3 bases as alumina and all the remaining bases as lime. (See Table I.)

It appears from the above ratios that in cement 1 after deducting 3 molecules of lime for combination with silica as tri-calcic silicate but .344 of a molecule is left for combination with .238 of alumina in the form of an aluminate. This corresponds very closely to the ratio demanded by $2Al_2O_3$ 3CaO, and to the molecular formula 42 (SiO_2 3CaO) 5($2Al_2O_3$ 3CaO), a molecular ratio of 23.8 aluminate to 100 of tri-calcic silicate. This might be

TABLE I.—Analyses of Cements.

	1. Per cent.	Molecular ratio.		
Silica	21.66	.3586	.3586	1.000
Alumina	7.01	.0686	.....	.....
Iron Oxide	2.57	.0167	.0853	.238
Lime	63.95	1.1400	.....	.....
Lime—minus SO_3 equiv.	.....	1.1230	.....	.....
Magnesia	2.60	.0666	.....	.....
Potash	.51	.0055	.....	.....
Soda	.25	.0040	1.1991	3.344
Sulphuric Acid	1.36	.0170	.....	.....
	100.00			

Alumina + iron oxide = R_2O_3
Lime — sulphuric acid + magnesia, potash and soda = MO
MO for R_2O_3 after deducting 3MO for SiO_2 = .344 for 238 R_2O_3

	2. Per cent.	Molecular ratio.		
Silica	22.64	.3748	.3748	1.000
Alumina	6.18	.0604	.....	.....
Iron Oxide	2.42	.0151	.0755	.201
Lime	64.89	1.1531	.....	.....
Lime—minus SO_3 equiv.	.....	1.1305	.....	.....
Magnesia	1.13	.0279	.....	.....
Potash	.63	.0067	.....	.....
Soda	.30	.0048	1.1699	3.121
Sulphuric Acid	1.81	.0226	.....	.....
	100.00			

MO for R_2O_3 after deducting 3MO for SiO_2 = .121 for .201 R_2O_3

COMPOSITION OF PURE CLINKER.

	1.	2.
Silica	22.2%	23.6%
Alumina	8.9	8.0
Lime	68.9	68.4
	100.0	100.0

assumed to exist as a solution of such an aluminate in such proportions in tri-calcic silicate.

In cement 2 after the same deduction enough lime is not left to form even a mono-calcic salt with the alumina. This necessitates the conclusion that some di-calcio silicate must be present and on this basis the formula for the pure clinker may be written, $18(SiO_2\ 3CaO) + 7(SiO_2\ 2CaO) + 5(Al_2O_3\ 2CaO)$.

Thin sections of clinkers of the composition which has been given were prepared. It was found on examination with polarized light that clinker No. 1 contained both alit and celit, that is to say, it was not a homogeneous solution of the aluminate, $2R_2O_3\ 3CaO$, in tri-calcic silicate. In the pure clinker No 2 the same structure was found, but a larger proportion of celit was present. This state of affairs opened up a new field of inquiry, as to what the structure would be of clinkers in which tri-calcic silicate and the various aluminates were present in a certain definite molecular ratio. The ratio 6 to 1 was chosen, it being well within the limit of what might occur in an industrial Portland cement, and the following clinkers were made:

$12\ (SiO_2\ 3CaO) + 2\ (Al_2O_3\ CaO) = 38\ CaO$
$12\ (SiO_2\ 3CaO) + 1\ (2Al_2O_3\ 3CaO) = 39\ CaO$
$12\ (SiO_2\ 3CaO) + 2\ (Al_2O_3\ 2CaO) = 40\ CaO$
$12\ (SiO_2\ 3CaO) + 2\ (Al_2O_3\ 3CaO) = 42\ CaO$

Thin sections of these clinkers showed that the one corresponding to the substance present as mono-calcic aluminate contained a very considerable amount of celit, that corresponding to the next higher degree of basicity, $2Al_2O_3\ 3CaO$, contained less, that corresponding to $Al_2O_3\ 2CaO$ still less, while that in which tri-calcic aluminate, $Al_2O_3\ 3CaO$, is supposed to be the form in which the aluminate is present contains no celit, but is a pure alit corresponding in every way with that seen in industrial Portland cement clinker.

The composition of alit is, in this way, entirely satisfactorily explained. It is a solid solution of tri-calcic aluminate in tri-calcic silicate. And on reduction it is readily seen that the di-calcic aluminate could not become dissolved in tri-calcic silicate without reaction going on and an interchange of base between the tri-calcic silicate and di-calcic aluminate to such an extent as to convert a portion of the di-calcic aluminate to the tri-calcic form and a corresponding portion of the tri-calcic silicate to the di-calcic form. The tri-calcic aluminate then dissolves in the tri-calcic silicate and the di-calcic aluminate in the di-calcic silicate, thus forming two separate and distinct solid solutions, the one alit and other celit, which while no doubt miscible in the molten condition, are not so in the solid form. In the same way the interchange of bases in the clinkers of less basic form where the amount of lime was only sufficient to account for the presence of mono-calcic or tri-calcic di-aluminate, would result in a similar state of affairs, but with a much larger percentage of celit as the basicity decreases.

The formula for these clinkers and the calculated amount of celit which they should contain would be as follows:

Series 6 Silicate 1 Aluminate

	(R_2O_3)	SiO_2	Al_2O_3	CaO
$12\ (SiO_2\ 3CaO) + 2\ (Al_2O_3\ CaO)$	38 CaO	23.7	6.7	69.6
$12\ (SiO_2\ 3CaO) + 1\ (2Al_2O_3\ 2CaO)$	39 CaO	23.2	6.6	70.2
$12\ (SiO_2\ 3CaO) + 2\ (Al_2O_3\ 2CaO)$	40 CaO	22.8	6.4	70.8
$12\ (SiO_2\ 3CaO) + 2\ (Al_2O_3\ 3CaO)$	42 CaO	22.1	6.2	71.7
Extreme difference in composition +		1.6	.5	2.1

These experiments, therefore, explain thoroughly the constitution of a pure Portland cement clinker. The presence of unessential elements, such as iron, magnesia and the alkalies, will produce an effect which does not affect the facts essentially, it may merely provide for the presence of some other more complicated solid solutions, although this seems improbable since the unessentials in an industrial clinker are apparently in solution in the celit, and although the presence of celit may be, perhaps, attributed to them.

In the same way as above the relative proportion of alit and celit can be calculated for a series in which the relation of silicate to aluminate is as 3 to 1, 4 to 1 and 5 to 1, and these wide ranges will cover all that will occur in industrial clinker.

Series 3 Silicate 1 Aluminate, or, 6 Silicate 2 Aluminate

	SiO_2	Al_2O_3	CaO
$6\ (SiO_2\ 3CaO) + 2\ (Al_2O_3\ CaO)$	21.5	12.1	66.4
$6\ (SiO_2\ 3CaO) + 1\ (2Al_2O_3\ 3CaO)$	20.8	11.6	67.6
$6\ (SiO_2\ 3CaO) + 2\ (Al_2O_3\ 2CaO)$	20.1	11.4	68.5
$6\ (SiO_2\ 3CaO) + 2\ (Al_2O_3\ 3CaO)$	18.9	10.7	70.4
Extreme difference in composition =	2.6	1.4	4.0

An increase in the lime in the case of the cement under consideration, No. 1, would have resulted in an increase in the amount of possible tri-calcic aluminate and consequently of alit and the cement would be slower setting. This has been found to be the case in clinkers produced in the laboratory, if they were burned at a sufficiently high temperature.

In the same way cement No. 2, to which a formula has previously been assigned, may be regarded as $15(SiO_2\ 3CaO)\ 3(Al_2O_3\ 3CaO) + 10(SiO_2\ 2CaO),\ 2(Al_2O_3\ CaO)$. This clinker contains nearly 1% less alumina, is a much less concentrated solution of the aluminates in the silicates than in clinker No. 1, but, on the other hand, it is much less basic and contains a larger percentage of the dilute celit, 30.8% as compared to 24.4. For the first reason the cement made for the No. 1 clinker should be slower setting than that made from the No. 2 clinker, but for the second the cement from the latter clinker should be less volume constant, since celit, being a di-calcic silicate solution, possesses the characteristic lack of volume constancy of that component.

Or as Alit and Celit

						% Celit
3	$(SiO_2\ 3CaO)$	$(Al_2O_3\ 3CaO)$	+	3 $(SiO_2\ 2CaO)$	$(Al_2O_3\ 2CaO)$	43.3
4	$(SiO_2\ 3CaO)$	$(Al_2O_3\ 3CaO)$	+	2 $(SiO_2\ 2CaO)$	$(Al_2O_3\ 2CaO)$	32.1
5	$(SiO_2\ 3CaO)$	$(Al_2O_3\ 3CaO)$	+	$(SiO_2\ 2CaO)$	$(Al_2O_3\ 2CaO)$	21.5
6	$(SiO_2\ 3CaO)$	$2(Al_2O_3\ 3CaO)$	All Alit			

Extreme difference in composition between two sets = 6 to 1 and 3 to 1 ..... 4.8 5.9 5.3

Series 4 Silicate 1 Aluminate

					% Celit
		Basicity of Al_2O_3 CaO			
5	$(SiO_2\ 3CaO)$	$(Al_2O_3\ 3CaO)$	3 $(SiO_2\ 2CaO)$	$(Al_2O_3\ 2CaO)$	34.1
		Basicity of Al_2O_3 2CaO			
6	$(SiO_2\ 3CaO)$	$(Al_2O_3\ 3CaO)$	2 $(SiO_2\ 2CaO)$	$Al_2O_3\ 2CaO)$	24.7
		Basicity of Al_2O_3 3CaO			
7	$(SiO_2\ 3CaO)$	$(Al_2O_3\ 3CaO)$	1 $(SiO_2\ 2CaO)$	$(Al_2O_3\ 2CaO)$	17.1

Series 5 Silicate 1 Aluminate

					% Celit
		Basicity of Al_2O_3 CaO			
7	$(SiO_2\ 3CaO)$	$(Al_2O_3\ 3CaO)$	3 $(SiO_2\ 2CaO)$	$(Al_2O_3\ 2CaO)$	28.1
		Bascity of Al_2O_3 2CaO			
8	$(SiO_2\ 3CaO)$	$(Al_2O_3\ 3CaO)$	2 $(SiO_2\ 2CaO)$	$(Al_2O_3\ 2CaO)$	21.0
		Basicity of Al_2O_3 3CaO			
9	$(SiO_2\ 3CaO)$	$(Al_2O_3\ 3CaO)$	1 $(SiO_2\ 2CaO)$	$(Al_2O_3\ 2CaO)$	14.2

It is evident that the relative proportions of alit and celit are dependent upon two variables, on the relation of silicate to aluminate and on the basicity of the clinker taken as a whole. It is also apparent that the ratio of 3 to 1 is an extreme limit in one direction, but that that of 6 to 1 in the other is not an extreme if industrial conditions could be accommodated to the production of such a clinker. It is also of interest to note that in the series 6 to 1 the extreme difference in composition between the different clinkers is so small, but 1.6 for silica, .5 for alumina and 2.1% for lime. In the series 3 to 1 the extremes are much larger and the differences 2.6 for silica, 1.4 for alumina and 4.0% for lime. This points to the fact that the regulation of the percentage of the various constituents in a clinker containing a large amount of alumina requires much more care than in one low in alumina. Between the two extremes series the greatest difference in composition are 4.8 for silica, 5.9 for alumina and 5.3% for lime. From this it may be calculated that the extremes of composition of an industrial Portland cement within the bounds of the above ratios, if the cement is perfectly burned, would be:

Silica ..... 18.5—23.2
Alumina (R_2O_3) ..... 6.1—11.9
Lime (without magnesia or alkalies) ..... 63.1—68.1

In practice our industrial clinkers do not reach the highest percentages of lime because the conditions available for their production commercially do not at present permit of it, and as a matter of fact they contain a larger proportion of celit than they would were it possible to do so. This is illustrated by calculating the theoretical percentages of celit in the clinkers prepared from pure chemicals, on the basis of the composition of the two cements which have been referred to.

To the pure clinker which was made to correspond to the cement which we have called No. 1, it was found that the molecular formula $42(SiO_2\ 3CaO)\ 5(2Al_2O_3\ 3CaO)$ could be assigned. On the alit and celit basis, after equilibrium has been established between the basicity of the silicate and aluminate, this formula might correspond to

Alit				Celit		
36	$(SiO_2\ 3CaO)$	1 $(Al_2O_3\ 3CaO)$	+	6 $(SiO_2\ 2CaO)$	9 $(Al_2O_3\ 2CaO)$,	or,
32	$(SiO_2\ 3CaO)$	5 $(Al_2O_3\ 3CaO)$	+	10 $(SiO_2\ 2CaO)$	5 $(Al_2O_3\ 2CaO)$,	or,
28	$(SiO_2\ 3CaO)$	9 $(Al_2O_3\ 3CaO)$	+	14 $(SiO_2\ 2CaO)$	1 $(Al_2O_3\ 2CaO)$.	

The latter form would be improbable, as, in that case, the celit would be too infusible owing to the small percentage of aluminate which it would contain, but in the other two cases the celit would be rich in aluminate, and on that account the cement would be quick setting, which was actually the case before it was plastered.

Which of the above formulas would be applicable here depends in any case, probably, on the rate of cooling of the clinker, and this explains why cooling at different rates may result in cement of very different properties.

Alit			Celit		% Celit
9	$(SiO_2\ 3CaO)$	$(Al_2O_3\ 3CaO)$ +	3 $(SiO_2\ 2CaO)$	$(Al_2O_3\ 2CaO)$	23.9
10	$(SiO_2\ 3CaO)$	$(Al_2O_3\ 3CaO)$ +	2 $(SiO_2\ 2CaO)$	$(Al_2O_3\ 2CaO)$	17.2
11	$(SiO_2\ 3CaO)$	$(Al_2O_3\ 3CaO)$ +	1 $(SiO_2\ 2CaO)$	$(Al_2O_3\ 2CaO)$	12.0
12	$(SiO_2\ 3CaO)$	$(Al_2O_3\ 3CaO)$			0.

From the preceding data it is evident that industrially we may have cements of different degrees of concentration as regards aluminates in the same way that steel exists of various degrees of concentration as regards carbon. As steel, low in carbon, is called a mild steel, and as there are cements corresponding to this, in that they contain relatively small percentages of aluminates, these may be very well called mild cements. With increase of the amount of aluminate they may be called medium cements, and with high aluminates hard cements. These designations it may eventually be necessary to modify to express variations in basicity.

The question now arises as to how concentrated the solutions of aluminates in silicate may become before the clinker ceases to be a normal Portland cement. Series of clinkers were prepared in which the components were tri-calcic silicate and tri-calcic aluminate, the proportions varying between 100% of the one and none of the other to the reverse through various percentages, in order to determine what the limits for the formation of alit are under such circumstances; of tri-calcic silicate and di-calcic aluminate to determine what effect a reduction in lime with a consequent increased formation of celit would have on the formation of alit and consequently on the formation of a normal Portland cement clinker and a series in which the components were di-calcic silicate and di-calcic aluminate for the purpose of determining the limitations of the existence of celit. The first series may be called the "Alit Series," the second the "Cement Series," and the third the "Celit Series," for reasons that are readily understood.

A microscopic examination of thin sections of the clinkers constituting these series has furnished results of the greatest interest, but which are too elaborate to go into detail in regard to in the present place. In a general way it may be said that the members of the celit series possess all the characteristics of celit, as it is seen in Portland cement clinkers made from pure chemicals, up to about the molecular ratio of six of silicate to one of aluminate, $6(SiO_2\ 2CaO)\ (Al_2O_3\ 2CaO)$, that at that ratio, or perhaps at somewhat wider one, a solid emulsion begins to appear as part of the section; at the ratio two to one $2(SiO_2\ 2CaO)\ (Al_2O_3\ 2CaO)$ the entire clinker consists of the solid emulsion, probably a eutectic, which begins to disappear again on the further concentration of the solution as regards aluminate, which phenomenon is accompanied by the appearance of cubes of the latter component before the ratio $3(SiO_2\ CaO)\ (Al_2O_3\ 2CaO)$ is reached, while the cubes become very prominent in the concentration represented by $2(SiO_2\ 2CaO)$, $3(Al_2O_3\ 2CaO)$ and still more so in $SiO_2\ 2CaO$, $Al_2O_3\ 2CaO$, these, of course, being solid solutions of the silicate in the aluminate. They naturally continue to increase as the concentration as regard silicate diminishes, but strangely possess a certain optical activity as if the dissolved silicate was not actually in solution in an isometric form,

but was mechanically held in the isometric aluminate in its own orthorhombic form. The eutectic at this end of the series also seems to be present in a form other than that of an emulsion. In this series the solubility of the silicate in the aluminate is much greater than that of the aluminate in the silicate.

Quite a different condition is found in the cement series. Here the normal alit-celit structure of two distinct solid solutions of different basicity is maintained up to the ratio $7(SiO_2\ 3CaO)$, $3(Al_2O_3\ 2CaO)$ as has been described for the pure Portland clinkers, but when the ratio $2(SiO_2\ 3CaO)$, $(Al_2O_3\ 2CaO)$ is reached there is a decided change in structure, the solution assuming the emulsion form corresponding to that of the clinker of the ratio $2(SiO_2\ 2CaO)$, $(Al_2O_3\ 2CaO)$ of the celit series and having a higher general optical activity, but an absence of a distinct seggregation of celit. This may, provisionally, be regarded as the eutectic of this series.

The Portland cement ratio may, therefore, be regarded as extending from:

	SiO_2	Al_2O_3	CaO
Pure tri-calcic silicate	26.4	0.0	73.6
to			
$7\ (SiO_2 3CaO)$, $3\ (Al_2O_3 2CaO)$	18.9	13.6	67.5

Beyond the latter degree of concentration the solutions or clinkers have not the structure of Portland cement and cannot be regarded as such although they are hydraulic.

The eutectic, in this series, must be considered as consisting not of an emulsion of saturated solid solutions of one definite silicate in an aluminate of the same basicity and of the same aluminate in the same silicate, as in the celit series, but as of four solutions, viz., of tri-calcic silicate in tri-calcic aluminate, of tri-calcic aluminate in tri-calcic silicate, of di-calcic silicate in di-calcic aluminate, and of di-calcic aluminate in di-calcic silicate. This is a complicated situation, but the globulites containing the excess of the optically active silicates can be differentiated from those in which the aluminate is in excess by their brighter interference in polarized light.

As the relative proportions of aluminate to silicate increase, $3(SiO_2 3CaO)$ $2(Al_2O_3 2CaO)$, a crystalline element appears again with a diminution in the amount of the eutectic. The crystals, which, theoretically, must be a solution of the silicate in the aluminate, as in the similar ratios of the previous series, possess some optical activity and can hardly be distinguished from alit in form or optical activity. In the ratio $SiO_2 3CaO$, $Al_2O_3 2CaO$ they are very well formed and the emulsion is still further reduced in amount, at the same time being seggregated again as groups like celit and having the optical activity of the latter. In the clinker in which the ratio is $6(SiO_2 3CaO)$ $4(Al_2O_3 2CaO)$ the structure is again completely changed. The main part of the clinker is an emulsion with a seggregation of cubical crystals of no optical activity. With continued decrease in the concentration as regards silicate the cubical crystals continue to increase and the optical activity to diminish. At the ratio $SiO_2 3CaO$, $6(Al_2O_3 2CaO)$ corresponding to the reverse ratio of that for Portland cement at the other end of the series, the aluminate is first found seggregated in the form of dendritic crystals constituting the larger part of the clinker, the material of higher freezing point still retaining some optical activity. The proportion of crystalline aluminate continues to increase on still further dilution as regards silicate, but a slight amount of optical activity remains in some particles with only 2% of silicate present.

In the alit series the alit form of the solution of tri-calcic aluminate in tri-calcic silicate persists through a wider range of concentration than in the two preceding series. The solutions present the low optical activity of alit, and, in fact, consist of pure alit of different degrees of concentration. A eutectic is found in all concentrations that have been prepared beginning with the ratio $6(SiO_2 3CaO)$ $(Al_2O_3 3CaO)$ and the cubical crystals of aluminate only appear at dilutions as regards silicate much greater than in the previous series, $2(SiO_2 3CaO)$ $8(Al_2O_3 3CaO)$. Needle-shaped crystals are present, possibly a definite compound, at certain concentrations.

This series has yet to be studied closely, however, the only definite conclusions, at present, being that at least up to the ratio $3(SiO_2 3CaO)$ $(Al_2O_3 CaO)$ it contains pure alit of different degrees of concentration and that tribasic silicate and aluminate of lime are more mutually soluble in each other than the di-basic salts or mixtures of the salts of different degrees of basicity.

Further studies of the three series of solutions will be presented in another place in greater detail.

It is evident that basic silicates and aluminates are miscible in all proportions at sufficiently high temperatures, that is to say, in a fused condition, but that they are not thus miscible in a state of solid solution. In the latter condition this results in the formation of heterogeneous solid solutions such as have been found in the various members of the series which have been described. What the solubility of the basic compounds of iron and lime are, as well as that of the magnesia salts, must be worked out later. It is known, however, that the iron compounds are not soluble to any extent in the basic lime silicates in the solid form. This, as will appear later, is an important fact in this connection, but it can hardly be taken up at this time with our limited knowledge of these solutions.

DIFFUSION.

Having determined that alit and celit are solid solutions of aluminates in silicates, the aluminates being present in less than an amount sufficient to make a saturated solution of aluminate in the silicate, it becomes of interest to consider how these solutions are formed during the conversion of a raw mixture or of a mixture of pure chemicals into a clinker. It would be simple to understand this if fusion took place in its formation, but this does not happen, the material is only sintered. If two gases are brought together they diffuse into each other with very great rapidity. If two liquids are poured one upon the other in layers without mixing, they diffuse more slowly. If solids are brought into contact it would be naturally assumed that diffusion would cease. Experiments of Robert Austin have shown that molecular mobility in solids exists, since when carefully polished surfaces of gold and lead are brought into contact and left under pressure for some months, at the ordinary temperatures, gold is diffused into the lead and the lead into the gold for an appreciable distance. Mixtures of the components which would produce a fusible Wood metal when subjected to pressure at ordinary temperature become converted into this alloy. Anhydrous sulphate of soda and carbonate of barium also diffuse when brought into close contact with the formation of barium sulphate and carbonate of soda. It is not difficult to understand, therefore, how at a temperature of 1650° C. the particles of silica, alumina and lime may diffuse below the melting point of the resulting clinker to form a Portland cement, and the fact that such a clinker is stable depends not only on its composition, but upon the fact that the diffusion has been complete, even in material which is only sintered. Sintering, therefore, may be defined as diffusion at a temperature below the melting point of the components or of the resulting solid solution. That diffusion under such conditions is surprisingly rapid is seen by placing a particle of ferric oxide on the surface of white Portland cement clinker, and then submitting it to a moderately high temperature. The rapid diffusion of iron through the white clinker can readily be noticed by the color which spreads through the mass. It is evident that the higher the temperature the more rapid the diffusion until it becomes very rapid on fusion. From this it may be concluded that the length of time during which it is necessary to expose any mixture of silica, alumina and lime to a temperature is a function of the temperature, and should be longer, the lower the temperature.

SURFACE CONTACT AREA.

There is another condition, however, of great importance and one which affects the rate of diffusion, and that is the area of surface of the different constituents which come in contact. Most investigators up to the time of the Newberrys were unable to prepare tri-calcie silicate or di-calcic silicate in a stable form. The Newberrys showed that if the materials, silica and lime, were finely enough divided there was no difficulty in forming a stable tri-calcic silicate. The writer has shown the same to be true in the case of the formation of stable di-calcic silicate. This result is not unexpected if the law of physical chemistry known as Fick's Law is considered. From a study of salt solutions of different degrees of concentration Fick determined that the "amount of salt which diffuses through a given cross section is proportional to the difference in concentration of two cross sections lying infinitely near each other, or is proportional to the difference in cross section."* This law has been shown by several investigators to apply to metals, and, no doubt, applies to all solids. If the surface area of the different particles entering into the formation of a clinker are not, therefore, great enough to provide a sufficient area of intimate contact for diffusion to be complete at the available temperature and in the allotted time, so that the resulting clinker is homogeneous in constitution the latter will not be in equilibrium or volume constant. This is a matter of great importance in the production of Portland cement, and together with the temperature and duration of heating makes up the conditions which must be carefully regulated in order to produce a stable clinker, that is to say, to bring about complete equilibrium without which a clinker on cooling will tend to rearrange its structure and dust.

OTHER CONDITIONS RESULTING IN LACK OF VOLUME CONSTANCY.

There are other conditions, however, which may cause instability in the solid solution. It can be readily imagined that as water in the case of many aqueous solutions may dissolve more of a salt at high temperatures, the silicate of lime may be able to dissolve more aluminate at high temperatures than will normally remain in solution in the cold. If such a solution is allowed to cool, the excess will separate out unless solidification is brought about so quickly as to prevent it. Should this take place the solid solution would be supersaturated, under appropriate conditions, and in a state of tension which would result in a tendency to return to equilibrium with a change of volume and breaking down of the clinker. It can be readily imagined that such a state of affairs can exist in industrial Portland cement clinkers which are rich in alumina. The conditions which aid in bringing about such a transformation are an increase in temperature, that is to say, the addition of heat. As in the case of hard steel, where heating it in different degrees according to the temperature attained results in withdrawing the temper so we can imagine that heating alit, which has been likened to the austenite of steel, may alter its structure. As a matter of fact normal when heated for some time to a red heat will not give a stable cement on grinding. Such a phenomenon as this may serve as an explanation of why cements change their rate of setting with age. A highly aluminous cement which, after plastering, will set in an hour, has often been found to set in three minutes when stored in closed freight cars for some time in a hot summer's sun. Here the temperature of transformation has probably been reached, the tension in the solid solution has been released, with the result that some aluminate is liberated which makes the cement quick-setting again.

*Elements of Physical Chemistry, Jones, page 244.

FINE GRINDING OF RAW MATERIALS.

With cement of normal composition the finer the grinding of the raw mixture and the more thorough the burning, the more complete the diffusion will be and the less tendency there will be towards a tension in the solid solution. As an illustration of this the ordinary Lehigh Valley clinker will set rapidly when first made. If the same raw mixture is ground to a much finer and more impalpable powder and burned in the laboratory, a clinker is obtained which yields a cement which does not set in less than one hour immediately after it is made. At the same time, such very fine raw material can be burned at a temperature more than 200° F. below that required for the coarser industrial mixture, and if burned at the usual high temperature fuses quite readily. This leads to the conclusion that a proper balance between fineness of grinding and fuel expenditure must be arrived at in order to reach the greatest economy. In the United States, where fuel is cheap, a coarser raw mixture of the character of that found in the Lehigh Valley may be burned than would be the case in Germany, where fuel being dear, it would be cheaper to go to a greater expense for finer grinding. On this basis we arrive at the theoretical conclusion that if a very finely ground mixture was submitted to a very low temperature, say 500° below that usually employed, for a very long time, say several weeks, the result would be as satisfactory a clinker as that now produced. It is probable that with the dome kiln the greater length of time of burning which is necessary is due to the fact that diffusion goes on much more slowly than in the rotary kiln and at a lower temperature. It also explains why that portion of the clinker which has not attained as high a temperature as that in the hottest part of the kiln dusts. Diffusion has not been complete, and the solid solutions are not in equilibrium. The higher the percentage of lime the higher the temperature which is necessary to produce complete diffusion in combination with silica, and the greater the necessity for a large surface area of contact. The finer the grinding of the raw mixture the higher the percentage of lime which can be carried.

It appears from the preceding that a proper chemical composition is no guarantee whatever that the cement will be a satisfactory one, as in such a case the materials of which it is composed may not have attained thorough diffusion and consequently not be in equilibrium.

The points which have been brought out by the investigations which have been just described are suggestive, but can only be considered as showing the possibilities of what can be done in the future. There is, of course, a very large field for further investigation, including more particularly the role which iron plays in the formation of clinker. There is no reason, however, why eventually the study of cements along physical lines should not afford as vast a fund of information as it has done in the case of iron and steel. It is the object of the writer to carry these investigations out on these lines in the future, and it would be a most appropriate thing if your Association should also contribute towards this work by establishing a laboratory or making a grant of funds to some committee of your body for the prosecution of such work. The United States might then lead in its scientific study of cement in the same way it now does in the character of its industrial product.

THE LARGEST LOCOMOTIVE REPAIR CONTRACT ever undertaken is said to be one just concluded between the Erie R. R. and the American Locomotive Co., for the repair of 600 locomotives at the shops of the latter company. This covers about half the motive power owned by the Erie company.

SMOKE AND GASES IN A RAILWAY TUNNEL caused the death of two men near Elkins, W. Va., on the West Virginia Central & Pittsburg Ry., July 19, 1904. A freight train became stalled in a tunnel six miles east of Elkins; while the rear engine ran part of the train back out of the tunnel, two trainmen on the remaining portion were overcome. The front engine cut loose from the train to get out into the open air, and the cars in the tunnel backed down grade and collided with the returning rear engine. The two trainmen who had been overcome by the gases were thrown off while the train ran away, and were killed.

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ADVERTISING RATES will be furnished upon application. "Want" and "For Sale" notices (special rates), see pages 26-27. The pages for new "Want" "Proposal" and "For Sale" advertisements are held open until Wednesday noon.

This being a time of year when camps of all kinds and likewise common flies are numerous, it seems appropriate to call attention once more to the fact that a combination of improperly cared for privies and the ordinary house-fly is one of the most fruitful means of spreading typhoid fever and some other intestinal diseases. The practical points to be observed and followed are: Continual disinfection of privies and latrines, frequent coverings of earth, and prompt burial or other sanitary disposal of stable manure, garbage and all other refuse in which flies breed. One of the most recent discussions of this subject was contributed to the June number of the "Journal of the Royal Army Medical Corps," by E. E. Austen, and abstracted editorially in the New York "Medical Record" of July 30, 1904.

The desirability of reducing the number of technical and municipal societies by consolidating those with similar objects, has often been urged in these columns. We are pleased to record the actual consolidation of the American Park and Outdoor Art Association and the American League for Civic Improvement under the name of the American Civic Association. Just how this was done and the constitution and officials of the new organization are set forth in Bulletin No. 1 of the American Civic Association, which can doubtless be obtained by addressing Mr. Charles Mulford Robinson, Secretary, Rochester, N. Y.

Another significant consolidation of engineering societies was proposed and unanimously endorsed at the Gas Congress at St. Louis last June. It contemplates nothing less than the merging of the many gas associations of the country in one national organization, with local chapters. As is well known, the American Institute of Architects has been successfully conducted for years with chapters all over the country. There seem to be many reasons why the gas associations should consolidate.

The American Society of Municipal Improvements holds its convention at St. Louis, and the League of American Municipalities meets at East St. Louis at the same time (Oct. 4 to 6) this year. Actual consolidation of these two bodies may not be feasible, or even desirable, but there is much to be said in favor of adopting the plan of holding their meetings at the same time and place, with one or more joint sessions. It might be arranged, if it has not been, to hold one joint session this year, say, with papers selected from each program. Those interested in such a proposition would do well to write to Mr. Geo. W. Tillson, Secretary of the American Society of Municipal Improvements, Municipal Building, Brooklyn, N. Y., and to Mr. John MacVicar, Secretary of the League of American Municipalities, Observatory Building, Des Moines, Ia.

Some of the most remarkable work ever accomplished in railway location and construction has been done in remote out-of-the-way parts of the world, where it has passed almost unnoticed by the public or the engineering profession. There is probably no region on the globe where the work of railway location and construction encounters greater difficulties than in the Andes of South America. To locate railway lines in this region within limits of grade and curvature that will permit their operation often taxes the best resources of the locating engineer.

We give large space in this issue to the work which has been successfully carried out through American enterprise and American engineering skill in building a railway to the summit of the Andes plateau in Ecuador. While not so remarkable a feat as the construction of some of the older Andes railway lines, it well merits the attention of engineers as a good illustration of difficult mountain location.

One feature of special interest in the proper description of this work is the statement regarding the methods of carrying on construction through a country commonly reported to be so unhealthful that residence in it was impossible. This had been, indeed, one of the great stumbling blocks in the way of building the railway line.

Had ordinary methods been pursued here there might have been serious trouble; but an organization was arranged at the outset designed to suit the conditions. A medical corps and hospital service was provided, careful sanitary regulations were enforced and every precaution was taken to prevent the outbreak of disease and cope with it if it occurred. The result was that the ordinary fatal disease of the tropics were kept in check. There is, it seems to us, a useful and encouraging lesson here with regard to work in the South American and Central American countries, of which a vast amount is, we trust, to be carried out by United States engineers during the next decade. By taking proper precautions, it should be possible to carry out these works without the sacrifices of life that have in the past been an important factor in discouraging Americans from enterprise in these regions.

The proper aspect from which to view the question of screw-spikes as rail fastenings appears to be with reference to the durability of the tie. Will the ties have enough longer life through the substitution of screw-spikes for driven spikes to repay the greater cost of purchasing and placing the screw-spikes? From present appearances the case in support of the screw-spike seems well established. The fact that European railways, which have to pay much higher prices for wooden ties than railways in this country, have long made extensive use of screw-spikes, is a strong argument in their favor. That the ordinary spike is a chief instrument in causing the destruction of ties is well known. Examination of any pile of ties removed from the track will show ties filled with spike holes, and also decayed spots starting from the point where a spike hole gave access to water.

At present and in the future it is entirely certain that railway ties in nearly all parts of the United States will cost so much that it will pay to take good care of them. It is a little more labor, of course, to bore a hole in a tie, dip a screw-spike in paint or tar, and screw it into the hole, than to sledge in an ordinary spike; but the first process leaves the tie practically uninjured so far as the entry of water is concerned, while the second process so bruises and crushes the fiber and so imperfectly fills the hole that water is pretty certain sooner or later to find access. With proper tools to set screw-spikes, the additional labor in placing them should count for practically nothing.

The only notable objection to the use of screw-spikes that we have seen is raised by Mr. Wm. Goldie, well known as an inventor of an improved spike. In a letter to the "Railway Age" Mr. Goldie claims that a screw-spike has such a hold in the tie that in case of unevenly tamped ties it will not pull a short distance as a spike does, but will raise a low tie from its bed and cause pumping of the ballast from under it.

Let us consider this objection. Suppose a spike is driven home in a low tie, and then pulled part way out again. Is such a rail fastening a safe one to hold a rail over which modern fast express trains are run? It would seem to us that if a tie is so poorly tamped that the ballast is pumped from under it, it is out of place in a track carrying modern heavy wheel loads and fast trains. On railways of light traffic, using ballast of such a sort that ties heave badly in winter and require shimming to keep the track in surface, there may be good ground for Mr. Goldie's objection; but it does not seem to us to apply to railways of heavy traffic where the demand is for a more secure form of rail fastening.

CONCERNING ENGINEERS' ESTIMATES.

It is often said that an engineer must devote years to obtaining an expensive education, to fit him to perform work requiring a high degree of technical knowledge, that he must roam from place to place to find employment, and often must spend a long time in idleness between engagements. Nevertheless, because of the number of capable men ready to take any promising position, the engineer when he finds work must often accept a rate of pay less than that of a skilled workman belonging to a union.

Those who control capital are not willing to pay high salaries for work which involves strictly and merely the technic of engineering. There are plenty of applicants to do such work, and employers are often unable to judge why one is not as good as another. The real importance of the technical work in connection with an enterprise is seldom appreciated by its financial managers. On the other hand, they are entirely willing to pay large salaries to men competent to take full executive responsibility, because they well know that on the management of an industry more than anything else depends its success.

We are led to this re-statement of a fact which we have presented in other forms by the very interesting paper on "Engineers' Estimates of Cost" by Mr. Samuel Whinery, which we print in this issue. Certainly, every engineer who values his own professional standing and appreciates the fact that it depends in no small degree on the standing of the profession as a whole, should read with care Mr. Whinery's able paper.

It is certainly true that the preparation of estimates of cost is one of the most important and difficult pieces of work that an engineer ever undertakes. Wherever this duty is imposed on an engineer, it is of itself evidence that he is filling the position he ought to fill. Such work is not "technical" work in the sense in which we have used the term, notwithstanding the fact that it requires technical knowledge. It is work that pertains to the conduct of business, and work for which there is little difficulty in securing adequate compensation.

Mr. Whinery is undoubtedly right in pointing out that the accuracy of engineers' estimates is often made by the public a test of the engineering profession as a whole; and the engineer who makes a careless or untrustworthy estimate is injuring not only his own professional standing but that of his brother engineers as well.

Manifestly, then, anything which will conduce to greater care and accuracy in the preparation of estimates is well worth the attention of engineers, and this is particularly the case, because it not seldom happens that such estimates leave much to be desired. Perhaps the most common fault of estimates is the tendency to "err on the safe side," as it is termed, by making the estimate so liberal that it can hardly be exceeded. As Mr. Whinery well points out, such estimating deserves criticism. It is true that on public works the engineer may make estimates of this sort and seldom suffer for it; but it is not so on

private work. Suppose a business firm desires to have a dam built, for example, and they ask an engineer to estimate what it will cost. When the engineer presents his estimate, suppose they proceed with the work under their own management, and find they can build it for half the money. That engineer's reputation will suffer quite as much as if he had underestimated the cost by an equal amount. Indeed, it may suffer even more, for the engineer who largely overestimates the cost of work is likely to be set down as an unpractical fellow, who would be likely to insist on finicky ways of doing work which would cause needless expense.

Of course there are occasionally cases where an estimate is desired to cover the outside limits of what a piece of work will cost; but in the great majority of cases where an estimate is called for it is for the purpose of ascertaining whether the work will or will not be worth undertaking. In any such case an overestimate may be as injurious as an underestimate. Again, one of the most common reasons for making estimates is to determine the relative advantages of alternative plans. Here it is manifest that accuracy in the estimates is all-important, and an overestimate is as bad as an underestimate.

No discussion of the subject of estimates would be complete, however, without reference to the matter of data for such estimates. We have seen that this is a class of work which tends greatly to increase the prestige and emoluments of the profession at large, and that for it to be of value, accuracy is all-important. But the engineer, when called on for estimates in a hurry, as is not seldom the case, is often at his wits' end how to make them. They cannot be evolved from his inner consciousness, and if the work happens to be something with which he is unfamiliar or out of touch, he must perforce take advantage of the experience of other engineers. If he can find this experience on record in professional literature he is fortunate; but the chances are that he will search long through the volumes of his favorite technical journal and find little to reward him. This is a defect of technical journals of which those who conduct them are well aware; but it will not be remedied until engineers as a whole come to appreciate the value to the profession at large of the publication of accurate figures of cost, put in such a form as to be most useful to another engineer desiring to estimate on similar work.

We are well aware of the difficulties which stand in the way of the publication of such figures. It is a time-honored custom to regard everything in the way of figures of cost as private business information, around which a mantle of secrecy must be thrown. As a matter of fact, however, if the men who interpose a negative to a suggestion to make public figures of cost were compelled to state explicitly in just what way their business would suffer from such publicity, in the majority of cases they would be unable to make a satisfactory reply.

On the other side, however, it can readily be shown that if general publicity were given to such figures of cost, the very firms which now refuse such publicity would be the ones to reap the largest benefit. The engineers would be enabled to do better work in this field; but the benefit from this better work would accrue chiefly to his employers.

Mr. Whinery's paper refers solely to the estimates of engineers for one side only of the ledger—the matter of cost. We would say a word here in advocacy of engineers' estimates for the other side—the matter of returns. We may best illustrate what we mean by the same piece of work which Mr. Whinery adopts as an illustration—the New York barge canal.

As our readers will recall, the question of whether that work should be undertaken or not hinged quite as much on its probable traffic and usefulness as upon its cost. At the time the question was under discussion we sought the opinion of a considerable number of prominent engineers on the broad question as to whether the canal, on the whole, should be undertaken; and we met in several instances the criticism that estimates of the future traffic and of the usefulness of the canal were outside the field of the engineer. His work ended when he had planned the canal and computed as closely as possible its cost. Estimates of its future traffic and of its commercial influence, we were told, belonged to the business man or the financier.

Now we shall freely admit that at the present day it is difficult to find engineers of such broad experience, mature judgment and range of vision that they are competent to prepare a reliable and trustworthy opinion upon such large and complicated questions as that which we have stated above. But is it not equally difficult to find other men who are any more competent? It is true the public is more ready to place confidence in the opinion on such matters of a financier, or a prominent lawyer, or the head of a manufacturing concern, or a successful merchant. But are such men, taking the best that can be found, so well equipped for such work and so competent to form a correct opinion as the engineer is, or ought to be? Admitting, as we may, the large ability of many of these successful men of affairs, it remains true that, for the formation of a sound opinion on many of these difficult questions of modern business, an intimate knowledge of technical matters is becoming more and more essential, and herein lies one advantage of the engineer who has had a good training and experience. Besides this, if the engineer has the necessary mental caliber, his work in the formative period of his life ought to develop and mentally broaden him as much at least as the work of the youthful merchant, selling goods over the counter, or the young bank clerk, spending his days counting currency and adding columns of figures.

We have taken the barge canal merely as an illustration. What we wish most emphatically to urge upon engineers everywhere is that they lose no opportunity to fit themselves for this most important and difficult work of estimating not only the cost of an enterprise but the revenues that may be derived from it, and that they seek such responsibilities wherever possible.

Doubtless the largest incomes enjoyed by engineers in any branch of the profession are those of the foremost mining engineers, and it is largely due to the fact that their work lies in the commercial field quite as much as in the purely technical field. The owner or prospective owner of a mining property is no more willing than other men to go beyond the market price in employing transitmen or analytical chemists; but he is willing to pay a great sum for the man whose knowledge and experience are sufficient to guide him safely in making a profitable purchase or sale.

In this field of estimating, as in that discussed by Mr. Whitney, caution should be used in separating the certain from the uncertain in preparing an estimate. In every enterprise the future revenues and profits depend much on business management, market conditions, general prosperity or adversity, development of competing interests, etc. Such uncertainties as these must be given full consideration in the preparation of the estimate, and their influence on the success of an enterprise should be clearly pointed out.

LETTERS TO THE EDITOR.

Plotting a Curve of Long Radius.

Sir: Having seen several articles describing methods for developing a curve having a long radius, suggests to me a method which is used by carpenters even when the radius is not to exceed 20 ft. Having the angle of the curve and the radius given, the chord subtending the angle can be obtained. Next place pins at each end of the chord and take a piece of cardboard of a length equal to twice the length of the chord. Lay off at the middle point of one straight edge of the cardboard an angle equal to half the angle of the curve subtended by the chord and cut this part off. Now, keeping these edges against the pins, the vertex of the cardboard will describe an arc of the circle desired.

Yours, S. T. Armstrong.

Sycamore, Ill., Aug. 4, 1904.

An Engineering School Modeled After West Point.

Sir: Referring to an editorial in your issue of June 2 entitled "Should Civil Engineering Schools Be Modeled After West Point?" permit me to quote from the closing paragraph:

"It still remains to put these theories into practice, as has been done at only one college of engineering, and that one, strangely enough, the oldest and most celebrated in the land—West Point."

I would respectfully call your attention to the fact that there is at least one other such institution—whose history and courses of instruction are set forth in condensed form on page 4 of Engineering News—Norwich University, the military college of the State of Vermont.

Norwich University is one of three institutions in the highest of the three classes into which all military institutions in the United States, excepting the Government academies, are divided by the War Department, and the character of the military as well as of the technical training is similar to that of West Point.

It is, perhaps, needless to say that the excellent theories advocated in your editorial are put into practice here, as at West Point.

Very respectfully, E. S. Ball.

44 E. 23d St., New York city, July 27, 1904.

Making Tape Measurements With One Man.

Sir: Now that the matter of tape measurements by one man has been mentioned in your paper, I am tempted to say a few words about it. I suppose that Mr. Badger's head chainman (see Engineering News of July 28, p. 92), after setting the forward stake firmly, with intent to ignore Shunk's rule that the rear chainman should hold his end by his own strength, and not by means of the stake, shakes the zero end free from the brad, winds or coils the tape up, applies the zero end to the forward stake and moves on.

I should say this would work fairly well, except when the rear end refused to be shaken off, and that the accuracy would be as high as with some wild animals I have known on the rear end.

For measuring for total length only, setting no stakes, a quart or two of common or garden clothes-pins may be bought, sharpened with a knife, and driven into the ground with the forked ends up, one at a time, as the lone chainman proceeds. A stick about 2 ins. long is lashed into the tape-ring crosswise. The first pin being set a few hundredths ahead of the starting point, the zero end of the tape is laid into the fork and pulled up until the stick engages it; then the tape is extended ahead and another pin set just ahead of the hundred-foot mark. A sharp pull upsets pin No. 1, and releases the zero end; the forward end is then laid into the fork of pin No. 2, and the tape moves on. This is fairly rapid, as the tape need not be wound up, and the pins are left to kindle the fires of the thrifty. Probable error, perhaps half a tenth in a hundred feet. Yours,

T. P. Perkins.

Boston, Mass., Aug. 2, 1904.

On the Lining of Concrete Sewers.

Sir: The inquiry of "M. L. C." this week about granitoid inverts in storm sewers is timely. The grades he mentions, 0.2 to 1.3 for sewers 4 to 6 ft. in diameter are good grades, and a flow would have considerable velocity. If it was laden with much silt and small stones the effect on the granitoid would be disastrous.

The bottom will work well and may work well for years, but it is only necessary to get one little start of a crack or hole and the bottom will go quickly. One of a gang of laborers said to the writer, "Concrete is strong on top and bottom, but d—— weak in the edges." About 20 years ago there was a big craze for concrete sewers and cement sewer pipe. It quickly passed and few engineers who lived to make sewers in those days look with favorable eyes on concrete sewers now.

Much has been forgotten of those times, and besides a new generation of engineers has arisen which makes better concrete and has better materials to work with. So the concrete sewer is coming back, and, thanks to the brickmasons' union, coming to stay. But the writer would use as an invert vitrified brick of the best quality or else use iron or steel. A very fine example may be seen in St. Louis, where a number of concrete sewers were built some years ago. The bottoms are badly worn, and this wearing is proceeding at a rapid rate, so the city is now putting vitrified brick inverts in these old sewers. A lot of vitrified brick sewers built at the same time, and earlier, have their original inverts yet, and are in good condition. In fact a vitrified brick invert seems not to wear, and if an occasional brick breaks it can be readily replaced.

The writer was speaking with an engineer who expressed surprise at the statement that concrete sewers were built many years ago, and he referred also to reinforced concrete as a material in use only four or five years. Truly a history of engineering is needed at our schools. The use of concrete for sewers goes beyond

any man's memory, and contractors were putting up buildings and sidewalks of reinforced concrete in San Francisco 23 years ago. Engineer.

Chicago, Ill., July 30, 1904.

Problems Raised by an Inverted Siphon in a Suction Main.

Sir: We are laying a 24-in. suction line from our pumping station to a new well and would like to have some suggestions from you as to the most scientific way of accomplishing our purpose.

We run from our pump station about 100 ft.; then drop 5 ft. in order to cross Lycoming Creek; then rise again on the other side and run about 200 ft. level to the well. This will give us an air chamber on the well side of the creek. What is the best way to overcome this difficulty?

We shut down our pumps in the winter time, as a rule, and this would leave us water in the low place in the line where it lays in the creek. How would be the best way to get rid of this?

Yours very truly,

Edmund B. Piper,

Supt. of the Williamsport Water Co. and Citizens' Water & Gas Co.

Williamsport, Pa., Aug. 1, 1904.

(Assuming that it is necessary or advisable to lay the suction pipe as an inverted siphon, two courses are possible to avoid trouble with air: (1) An air pump may be used to create and maintain a vacuum or (2) a check valve may be placed on the foot of the suction pipe in the well, and an air chamber may be put on the suction pipe between the creek and the well. When it is desired to start the pump the air chamber may be opened and the suction pipe filled with water. This air chamber will be a distinct benefit in such a long suction pipe in any event. To drain the bottom of the inverted siphon in winter perhaps a steam jet pump would be as simple an arrangement as could be used.—Ed.)

The Work of the Hydraulic Dredge "J. Israel Tarte."

Sir: I was very much interested in the account of the hydraulic dredge "J Israel Tarte," published on page 83 of your issue of July 28. In this article it is stated that the place measurement is 80% of the scow measurement. This is equivalent to an increase of 25% over the place measurement, which seems to me a very large one.

On page 145 of my paper on the Buffalo, N. Y., breakwater (Trans. Am. Soc. of C. E., Vol 52), referring to the large trench dug for the Stony Point Section, the increase of scow measurement over place measurement is given as 7.6%.

The place measurement was determined from *absolute* cross-sections, taken every 10 ft. longitudinally by means of a very elaborate sounding scow. Apparently the material excavated at both places, Buffalo and the St. Lawrence River, seems to be very much alike, except in the former case it was red clay and at the latter place blue clay.

On page 44 of your supplement, same date, I note an item that the Dominion Government of Canada has just appropriated $65,000 for repairs of this dredge, viz., the "J. Israel Tarte." Yours truly,

Emile Low, M. Am. Soc. C. E.

33 Mann Bldg., Utica, N. Y., July 30, 1904.

(Proof of the above letter was submitted to Mr. Robinson and we append his reply.—Ed.)

Sir: Referring to Mr. Emile Low's letter would say that the quantity of excavation measured in place of the dredge "Tarte" was increased in the proportion stated to compare with the results of the other dredges on the work which load into scows. The proportion of 80 to 100 holds good from actual observation of these dredges, and covers not only the fact that the clay is at times in large lumps in the scows, but also imperfect filling.

As to the item of $65,000 for repairs, would say that this is a special appropriation covering "extraordinary" repairs consequent upon the explosion of one of the boilers, which is referred to in the paper. It covers four new boilers, aggregating 2,000 HP., and almost complete rebuilding of the deckhouses, making them more commodious. It does not affect in any way the ordinary repairs nor the dredging apparatus.

Yours very truly,

A. W. Robinson.

14 Phillips Square, Montreal, Canada, Aug. 4, 1904.

Failure of Riveting in Plate-Girder Flanges.

Sir: In reply to Mr. G. A. Glascott in your issue of July 28, I beg to state that several instances of the failure of deck plate girders from insufficient rivets in the top flange have occurred within my observation. The failure occurred in the top flanges only, showing that the direct load from the track was the determining factor.

The worst case that I have in mind was a girder built on an English design with very thin web and comparatively heavy flange. The flange rivets were 4-in. pitch throughout and the stiffeners were bent outward and riveted to the very wide flange plates. These stiffeners were about 4 ft. apart. There were 16 girders of about 40-ft. span in the bridge and the top flange of a few of them became loose on the webs between the stiffeners. This looseness ranged from a mere cracking of the paint at the edge of the flange angle to ¼-in. movement under each wheel of the train as it passed over. There seemed to be but little difference between the center and ends of girders in the amount of looseness. The rivets were perfectly tight in the angles and when cut out showed a groove about ⅛-in. deep cut by the web on the lower side of the rivet. Probably the web was equally worn so that the total motion was ¼-in.

The failure of girders from this cause is very gradual and there is no danger of collapse. I know of many girders where this action has commenced and it seems to occur at the middle as soon as at the ends of a girder. It is the only way in which I ever knew a plate girder to fail except by corrosion. Wheel loads on deck plate girders certainly ought to be provided for in the top flange rivets, but we find many specifications which call for the same number in top and bottom flanges with no distinction between deck and through plate girders.

Yours truly, J. P. Snow,

Bridge Engineer, Boston & Maine R. R.

Boston, Mass., July 30, 1904.

(This letter also bears on Mr. Glascott's second question, viz., Why should loose rivets be considered an indication of excessive bearing pressure, when it would seem that any deformation of a rivet would tend to make it still tighter? Mr. Snow's observation shows that a rivet may be under pressure great enough to cut a groove in it, and become loose enough to move under passing wheel-loads instead of becoming "still tighter." Evidently, friction between the plates does not add very greatly to the strength of the joint; but precise data on this matter would be of value.—Ed.)

The Patent Infringement Suits of the American Sewage Disposal Co. Against Plainfield and Pawtucket.

Sir: The suit to test the validity and scope of the patent No. 559,522, issued by the United States Patent Office May 5, 1896, to Amasa S. Glover, was commenced in the Circuit Court of the United States, District of New Jersey, by the American Sewage Disposal Co. of Boston, by a bill of complaint against the City of Plainfield, N.J., filed April 10, 1902. The answer was filed July 7, 1902. The replication was filed Aug. 4, 1902. The taking of testimony was commenced before a special examiner Nov. 11, 1902, and was continued from time to time until it was closed May 13, 1903.

The above statements are matters of record in the United States Court.

The next record in the case appears in Engineering News, of July 28, 1904, by which it appears that the city authorities of Plainfield contracted with the Cameron Septic Tank Co., of Chicago, July 5, 1904; the company to receive $4,000, and be responsible for the "resulting judgment against the city" (if any—Ed.) in the above-mentioned suit. "The city also specifically acknowledged the validity of the patents."

To revert to the Court records. Jan. 14, 1903, a bill of complaint was filed by the American Sewage Disposal Co. of Boston against the City of Pawtucket, R. I., in the Circuit Court of the United States, District of Rhode Island. Defendant's answer was filed Feb. 2, 1903. The replication was filed April 9, 1903. The trial of the case, by the taking of testimony, commenced July 15, 1903, and was continued from day to day, week to week, month to month, with only the necessary interruptions, until June 28, 1904, when the printed evidence and exhibits, numbering 827 pages, and the briefs (pp. 128, pp. 69, pp. 15), were finally presented to the Court for adjudication of the case.

On July 15, 1903, all the evidence taken in the Plainfield case was stipulated into the Pawtucket case.

Your article conveys the impression to the public that the American Sewage Disposal Co. of Boston, has not been pressing their test patent suit; whereas the court record shows the contrary.

With your permission I wish to give a hint to my brother engineers and municipal authorities generally.

If it is proved in the Rhode Island District that Amasa S. Glover was the discoverer of the value of putrefaction in sewage disposal, and the inventor of the combination of putrefaction and oxidation beds in sewage disposal, that point is settled wherever the American flag indicates American sovereignty.

I am of the opinion that Plainfield will have great difficulty in collecting more than $4,000 from the Cameron Septic Tank Co., even if the judgment against the city amounts, as claimed, to $8,000; for the reason that it can be shown that the city officials are gambling with public money; not on a prize fight, a horse-race, or even an election, but on the decision of the most august tribunal in this country.

Moreover it can be shown that the officials are not even betting fair, because they have inside information.

The City of Plainfield has been sued by two companies with conflicting patent claims. The honorable City Council of Plainfield "specifically acknowledged the validity of the patents" of one claimant. They were all right in paying the $4,000—if the deal holds; but they are exceeding their constitutional authority when they come to decide upon the validity of a United States patent.

John N. McClintock, A.M., C.E.,

President and General Manager of the American Sewage Disposal Co. of Boston.

643 Old South Building, Boston Mass., July 30, 1904.

The sooner the Plainfield and Pawtucket suits are brought to a trial, so that a court decision can be rendered as to what bearing the Glover patent (No. 559,522) has upon certain processes of sewage treatment, the better will it be for the public. In the interests of the public, also, it is a pity that the suit brought against Plainfield by the Cameron Septic Tank Co. was not brought to trial instead of being compromised.

The title to the article in our issue of July 28, 1904, entitled "A Compromise of One of the Septic Tank Infringement Suits at Plainfield, N. J.," was perhaps misleading in that it conveys the idea that patent No. 559,522, now controlled by the American Sewage Disposal Co., purports to cover the septic tank. In the text of the article, it will be noticed, reference was made to this patent merely as one on a process or processes of treating sewage. We may also note that, according to the foregoing letter, the American Sewage Disposal Co. brought suit against Plainfield in 1902, instead of in 1903, as we stated in our issue of July 28, 1904.

The claim in patent No. 559,522, granted to Amasa S. Glover on May 5, 1896, and made the basis of the above-mentioned suits against the cities of Plainfield and Pawtucket, is so brief that we reprint it here for the benefit of such readers as may not have a copy of the patent at hand:

I claim:

A sewage apparatus comprising a series of stationary primary filter beds, a structure over said beds with provision for the removal of offensive gases therefrom, and a series of stationary secondary filter beds located outside said structure and arranged to receive by gravitation the effluent from the primary filter beds, the said primary beds being constructed to discharge the effluent wholly through filtering material, whereby the offensive matter is retained in the structure and the effluent is clarified and partially purified, and whereby the said effluent may receive subsequent treatment in the open air by extensive secondary beds for any required length of time without offense.

The patentee declares, in the usual opening paragraph of the specification, that "this invention has for its object to permit the filtration of sewage on a large scale without making the same offensive."

The specification contains two brief paragraphs relating to a possible tank, the first of which is as follows:

The sewage may be (before going to the primary bed—Ed.) first deposited in a settling tank, which may be within the structure (the one housing the primary bed—Ed.) or elsewhere, and after sedimentation or chemical precipitation in said tank the liquid and the sludge may be drawn off onto the primary filter beds.

The following paragraph states that the settling tank is not shown in the patent drawings, but may be assumed to be located below the primary bed.

The specifications call for no particular kind of filtering material for either set of beds, nor for any special arrangement thereof. They describe a water-tight bottom for the secondary bed and a similar bottom as permissive for the primary bed.

It is particularly interesting to note that the specifications contemplate the necessity of removing from the primary bed the solid matter retained by it, and speak of composting it with ashes, loam or sand and removing it without offense.

In a much earlier and now expired patent (No. 258,744, granted May 30, 1882), Mr. Glover claimed the invention of a combination of series of settling tanks, through which the sewage flowed successively, an enclosing building, a ventilating flue and shaft to carry off odors from the tanks and means for shutting off the sewage from any tank in the series for purposes of cleaning. In his specification he admitted the prior

use of settling tanks in series, but "was not aware that such tanks have ever been covered by a structure having an inclined roof or flue leading to a chimney, whereby all offensive odors and noxious gases are sufficiently removed as to be harmless."

We have been led to give considerable space to these patents in view of the apparent breadth of the claims made or intimated by Mr. McClintock in his letter, particularly in the fourth paragraph from the end. It has not been our intention to prejudge the claims, but merely to let our readers know how the patents themselves read.—Ed.)

STANDARD GIRDER-RAIL TRACK CONSTRUCTION FOR CITY STREETS, PENNSYLVANIA R. R.

The accompanying drawings show the track construction for city streets recently adopted by the Pennsylvania R. R. for its Delaware Ave. freight lines in Philadelphia, Pa. In this construction a girder rail weighing 141 lbs. per yard was used. This is considerably the heaviest construction for railway track of which we have knowledge. Referring to the drawings, Fig. 1 shows a cross-section of one of the rails at the joint, which is twelve-bolt angle-bar supported joint. Fig. 2 is a transverse section through the completed track. The rails are spiked to wooden ties spaced 2 ft. ¾ in. apart, c to c, and are also tied together by tie rods spaced 5 ft. 6 ins. apart. The other details of the construction are shown by the drawing.

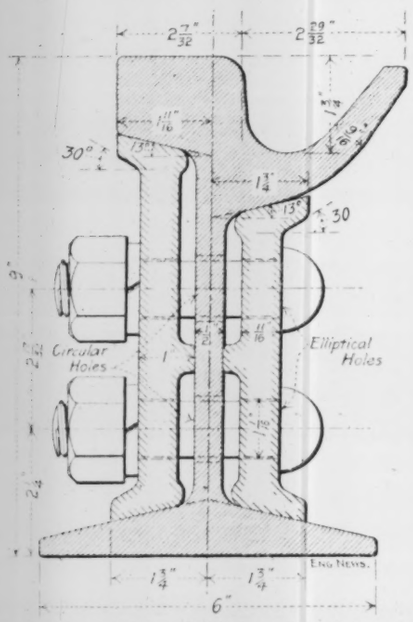

Fig. 1. Cross-Section of 141-lb. Rail and Joint for Track in City Streets, Pennsylvania R. R.

The Delaware Ave. freight tracks, on which the construction illustrated is employed, extend from Race St. to Washington Ave., and are intended to accommodate the fruit and produce commission merchants. They will be used jointly by the Pennsylvania, the Philadelphia & Reading and the Belt Line railways, each of which assumed one-third of the cost of their construction. The rails were rolled by the Pennsylvania Steel Co., of Steelton, Pa. For the information from which this description has been prepared, we are indebted to Mr. Joseph T. Richards, Chief Engineer, Maintenance of Way, Pennsylvania R. R.

RAILWAY PROGRESS IN CHINA.

Mr. John C. Ferguson, a Massachusetts man by birth, and one time President of the Nan Yang College at Shanghai, but now Chief Secretary of the Chinese Imperial Railway Administration, is in this country on railway business. From a lengthy interview published in the Washington "Star," we glean the following notes relating to the present railway status in China:

The railways of North China are well known, as the initial road from the Kaiping coal mines to Tientsin was opened ten years ago. This line was later extended to Pekin and northward to a connection with the Chinese-Eastern Railway and thus with the Trans-Siberian system.

The Peking-Hankow is being built by a Belgian syndicate, and is now completed as far south as the Yellow River. The Belgians are also working from Hankow northward, and they expect to connect the two sections at the Yellow River about the end of 1904. Plans have been made for the bridge over the Yellow River, but work has not been commenced upon it.

No work has yet been done on the Anglo-German railway from Tientsin down through the western part of the Shantung province. This line strikes the Grand Canal and is located along this canal to Chinkiang on the Yangtse River. It will be an important trunk line when built. It would connect with the line that passes through Chinan-fu, the capital of Shantung, and with the railway the Germans are building from Kiaochow Bay into the interior, and it will open up extensive coal fields. About two months ago the Germans opened their line connecting Kiaochow with Chinan-fu; by the old methods of travel this trip required from 12 to 15 days; it is now made in 12 hours. This latter line passes through the Weihsien coal fields, giving this product an outlet to the sea; it also goes by Taishan, the most noted of China's sacred mountains, and passes the old home of Confucius, and will thus be much patronized by pilgrims.

In Southern China the most important concession was granted to the American-China Development Co., which proposed to build a line from Hankow to Canton, thus completing a through line from Peking to Canton. It will open up regions rich in coal, iron, copper and antimony, the greater part of the antimony of the world coming from this locality. About 40 miles of track have been built west of Canton and the line should be finished in four to five years. The concession and property has been transferred, however, to a Belgian company.

British capitalists are interested in other lines. One trunk line will go southward from the Yangtse River, connecting with the Anglo-German syndicate line and passing from Nanking to Shanghai; construction is to be commenced at an early date. It will pass through some of the most populous sections of China and it will probably be extended southward to Hangchow, the center of the silk trade. The Shanghai-Wusung road, already built by the Chinese, will form a part of this line.

The French are extending their lines from Tonkin across the borders of Tunnan and Kuelchow, and thus reach the rich mineral deposits of these two provinces—coal, iron and great copper mines.

Western China, or the country beyond the gorges of the Yangtse-Kiang River, is still comparatively unknown to the outside world. It possesses a rich soil and vast mineral resources. Syndicates are now endeavoring to obtain concessions for railways leading into this section; and especial efforts are being made to secure the right to built a road from Hankow, through the mountains, to Chung-King, in the Szechuan province, and on to Chengtu, the capital of this province. While both the Yellow River and the Yangtse River have their rise in this part of China, their course through the mountains is so broken by rapids that navigation is impossible. As a consequence the country now has no outlet.

Mr. Ferguson believes that the completion of these railways will greatly aid in unifying the Chinese people, and in breaking up the many dialects spoken. The Chinese are more favorable to railway building than they were a few years ago; they begin to realize their advantages and largely patronize the lines already built. Mr. Ferguson remarked that during the great examination held last year at Kaifeng-fu, the capital of Honan Province, thousands of students used the railway from Hankow north to Sinyang—the then terminus. But the other half of the journey had to be made by mule carts; and when the students found that this last half would cost them about thirty times more than the railway half, some 6,000 students refused to undertake the hardships of the journey and returned by railway. This is an important object lesson; and these students who ten years ago would have written essays against railways, regarding them as a piece of Western impudence, are now among the most enthusiastic advocates of modern methods of travel.

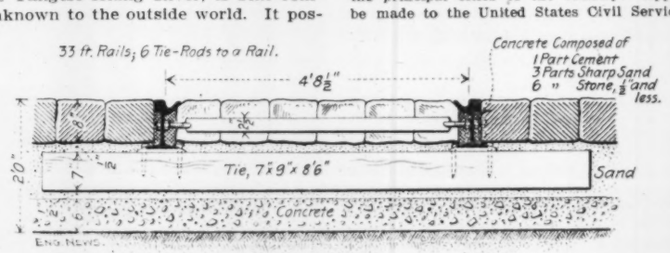
33 ft. Rails; 6 Tie-Rods to a Rail.
Concrete Composed of 1 Part Cement 3 Parts Sharp Sand 6 " Stone, ½" and less.
4'8½"
Tie, 7"x9"x8'6"
Sand
Concrete
ENG. NEWS.

FIG. 2. DETAILS OF TRACK CONSTRUCTION FOR CITY STREETS, PENNSYLVANIA R. R.

A RAILWAY WATER TANK FAILED at Tiffin, O., in the yard of the Baltimore & Ohio R. R. on July 29. The fall of a hoop from the tank in the early morning was soon followed by the bursting of the tank, with damage to a part of the depot and serious injury to an express agent.

TIMBER TESTS, experiments on seasoning and preserving timber of various kinds, studies of forest fires, and working plans for the improvement of private forests are among the assignments of the staff of the Bureau of Forestry, U. S. Department of Agriculture, for August, 1904. A "Field Programme" showing these assignments has been issued by the bureau. Mr. Gifford Pinchot, Washington, D. C., is Forester.

A VERY DISASTROUS RAILWAY ACCIDENT occurred on the Denver & Rio Grande Ry. near the town of Eden, a few miles north of Pueblo, Colo., on Aug. 7, 1904. An eastbound through passenger train, known as the World's Fair Flyer, broke through a bridge crossing a flooded creek. Two sleepers and a diner, which formed the rear of the train, remained on the track, but the whole forward part of the train went into the river. At least eighty persons, possibly, a hundred, were killed by being crushed in the wreck or by drowning. The bridge (or trestle?) crossed Steele's Hollow or Dry Creek, and is said to have been only fifty feet long. It is reported that when the train reached the bridge, running slowly, the water was level with the track. When the engine had not yet fully crossed the bridge, the structure failed. A news dispatch states that two hours after the accident there was no water in Dry Creek.

AN EXAMINATION FOR ENGINEER DRAFTSMAN in the Supervising Architect's office will be held on Sept. 14, 15 and 16, 1904 (this examination was some time ago fixed to take place on Aug. 17 to 19, but the date has been postponed as noted). The position to be filled pays $1,200 per annum. Candidates must be at least 20 years old. Examinations may be held in most of the principal cities of the country. Application should be made to the United States Civil Service Commission, Washington, D. C., or to the secretary of the local civil service board, in time to allow examination papers to be shipped to the proper officers at the place of examination.

FREE EMPLOYMENT OFFICES are maintained at three places in Chicago and one in Peoria, Ill., by the State Bureau of Labor Statistics. The offices were first established in 1899. The work accomplished in 1902-3, and from 1899 to Oct. 1, 1903, was as follows:

	1903.	Total, 1899-1903.
Applications for employment	43,510	166,397
Positions secured	39,227	141,119
Applications for help	47,559	169,092
Help secured	39,477	141,119